THE STORY OF ASTRONOMY IN INDIA

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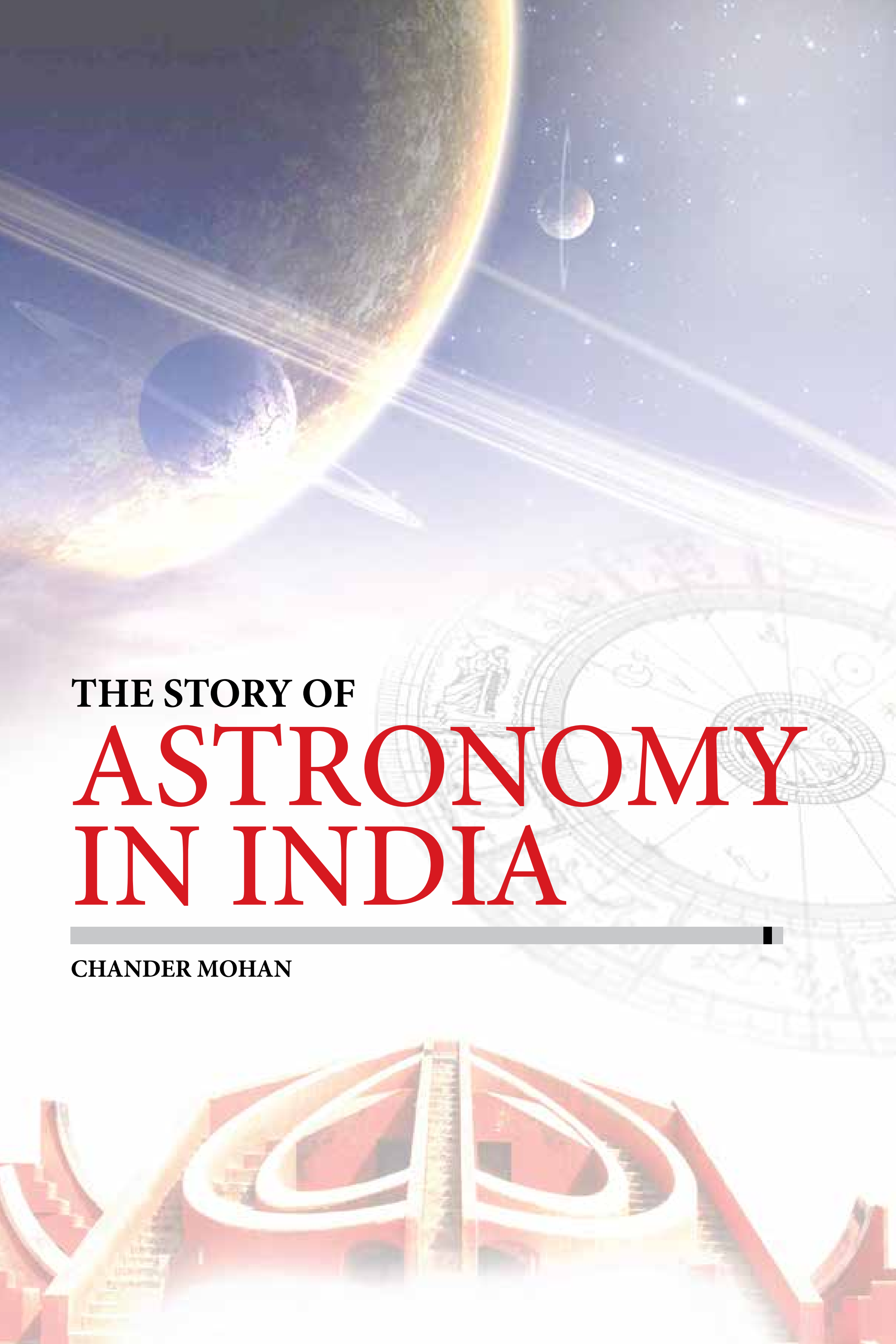

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Dedicated to the Sweet Memory
of
Late Dr. Chandrika Prasad

Preface

My object in writing this book has been to take the reader on a guided tour of the origin, growth and evolution of astronomy in India through ages. The book has been written from a layman`s point of view who does not have any specific knowledge of astronomy. The author was in fact motivated in writing this book after he read the book on the history of Indian astronomy titled `Bhartiya Jyotish ka Itihas` by late Dr. Gorakh Prasad. This book is in Hindi and was published by the Publication Bureau of Uttar Pradesh Government way back in mid fifties of the twentieth century (1956), and is perhaps now out of print.

Dr. Gorakh Prasad was an eminent mathematician and astronomer of his times. He had done his doctorate in an astronomy related subject from U.K. and was teaching in the department of mathematics at Allahabad University. After independence, the government of India had appointed a committee to suggest a national calendar which should be acceptable to all in India. Dr. Gorakh Prasad was a member of this committee.. It was on the recommendations of this committee that the Indian Government adopted Saka Era as the national calendar. However this calendar could not get as much acceptance from the public as was expected. In fact these days the dates based on this calendar are mentioned only in government gazettes and on national radio and television each day.

Prof. Gorakh Prasad was the father of Prof. Chandrika Prasad, again an eminent mathematician and theoretical astronomer of his times. He was the founder head of mathematics department at Roorkee University and remained at the helm of its affairs for around three decades. Like his father, he had also done his Ph.D. on a topic of theoretical Astronomy from U.K. in 1950. The author had the privilege of working under Prof. Chandrika Prasad for his Ph.D. on the topic of the pulsation theory of variable stars in the field of theoretical Astrophysics, as well as of working with him as a colleague in the Mathematics Department of Roorkee University for several years. Prof. Prasad retired from Roorkee Univerity in 1980. While leaving Roorkee, Prof. Prasad gifted the author an original copy of his Ph.D. thesis as well as a copy of the book on the history of Astronomy in India by his late father Dr. Gorakh Prasad.

After going through this book, the author got the motivation to write the present book in order to acquaint the common people with the story of the evolution of Astronomy on Indian subcontinent through ages. The author has the feeling that since the book by late Dr. Gorakh Prasad on the history of Astronomy in India is in Hindi and had been written long back (and even might be now out of print), it would be worth while to write a somewhat similar book in English for the benefit of a wider audience. The book is primarily in a narrative form meant for a common type of reader.

In writing this book the author has liberally drawn upon the contents of the book by late Dr.Gorakh Prasad as well as certain other similar books available on the subject and certain relevant material available in different websites on the internet.

C. Mohan

Ambala, June,2015.

CONTENTS

1. Introduction 1
2. Prehistoric Era 16
3. Astronomy in Vedic Era 19
4. Vedang Jyotish 30
5. Astronomical References In Religious Scriptures 36
6. Astronomies of the West 43
7. Arya Bhatta-I 49
8. Panch Siddhantika of Varahamihira 53
9. Surya Siddhanta 61
10. Varahamihira to Bhaskar Acharya-II 72
11. Siddhant Shiromani of Bhaskar Acharya-II 78
12. Bhaskar Acharya-II to Jai Singh 85
13. Jai Singh and his Observatories 92
14. After Jai Singh 97
15. Interaction with the Astronomies of the World 103
16. Modern Era Astronomy 107
17. Our Universe 112
18. Cosmology 120

Appendices

1. Panchang Horoscope and Astrology 126
2. Siddhantas, Karnas and Koshtakas 137
3. Observational Instruments of Indian Astronomy 140

01

INTRODUCTION

1. Advent of Astronomy

Ever since the appearance of human race on earth in the distant past, humans have marveled and felt fascinated and excited on observing the sun, the moon and the stars in the sky and their rising and setting. Each morning the sun rises in the east, gradually moves upwards in the sky, and then starts coming down towards the west in the afternoon, finally setting in the western horizon in the evening. After the sunset, stars appear in the sky. They also move from east to west. As the night advances, new stars come above the horizon in the east and stars that have approached the western horizon set there. Humans must have also marveled and wondered at the moon. Its periodic waxing and waning as well as shifting in its position in the sky from day to day at the time of its rising.

Gradually as the human race evolved and became aware of grain growing grasses, people started living in helmets and villages instead of living in jungles and caves. Instead of depending upon hunting and naturally growing plants and fruits for subsistence, they started cultivating land and growing crops and domesticating animals.

It was perhaps at this stage that the humans felt the necessity of knowing the rudiments of the subject which we now call astronomy, so that they could make use of this to know in advance as to when to sow a particular crop and when to reap it. For this it was necessary to keep a record of the passage of time. And for keeping the record of the passage of time, it became necessary to observe natural phenomena that repeat themselves periodically.

Ancients must have noticed that day and night alternate without fail. This phenomenon is regular and periodic. Also the sun always rises in the east and sets in the west. However its position of rising and setting in the horizon keeps on shifting. At first it gradually shifts south and after having reached an extreme position in the south, it starts gradually shifting back north. Moreover, not only the position of its rising and setting, but also the time of its rising and setting changes periodically.

In the case of the moon it must have been noticed that at first it appears as a crescent in the western sky in the evening. Then the position of its appearance in the evening in the sky starts shifting gradually east. Moreover its shape also waxes from day to day till after a fortnight a full moon rises in the eastern horizon at sunset. After this its shape starts gradually waning. It also starts rising more late each night for the next fortnight. The cycle is completed and it reappears again as a crescent in the western sky in the evening after about a month. And all this is periodic. Such periodic changes in the observed behavior of the sun and the moon must have prompted humans in the distant past to use these to evolve suitable measures for the record of the passage of time.

In the case of the stars, it must have been noticed that the stars appear in the sky after sunset and as the time passes, they gradually move from east to west. New stars rise in the east and stars getting closer to the western horizon set there. Each evening practically the same set of stars become visible in the sky at their previous positions. Excepting a few stars, their relative positions do not change. Ancients must have also observed some star clusters and a hazy whitish milky patch stretching across the sky from north to south. Ancients must have not only been awe inspired and wonderstruck by these natural phenomena but must have also felt the urge to understand these natural phenomena and if possible to put this knowledge to practical use in day to day life. This eventually must have lead to the evolution of a subject of study which we now call Astronomy.

2. Astronomy and Astrology

Astronomy is concerned with the observation of heavenly objects such as the sun, the moon, the stars, their times of rising and setting, the waxing and the waning of the moon, changes in the relative positions of certain observed stars, trying to understand the causes behind these observed phenomena and if possible to put this knowledge to practical use in the service of mankind.

It seems that later on when common people noticed that a few learned scholars could predict with reasonable accuracy, the times of rising and setting of the sun, the moon and the stars and the onset of different seasons and even eclipses of the sun and the moon, they started believing that perhaps with the knowledge at their command, these learned experts could also predict an individual’s future. This might have lead to the development of a subject which is now called Astrology. As a consequence the scientific study of astronomy got mixed up with astrology for which there is perhaps no scientific base. In fact in the past, astrology has always acted as an impetus for the evolution of astronomy.

Even to this day not many appreciate the difference between astronomy and astrology. Whereas astronomy is the scientific study of the observed natural phenomena happening around us in the sky, astrology is concerned with using this information to predict the future of a person. In fact the Sanskrit word `Jyotish` applies to both astronomy and astrology.

Astronomy as a discipline evolved differently in different parts of the world even though the basic fundamentals have been same everywhere. Climate, topography, necessity and local requirements influenced to a large extent its evolution and growth.

As is expected of an ancient civilization, India also has a long history of the evolution and growth of astronomy, traditions going back to the hoary distant past.

3. About the book

The object of the author in writing this book is to familiarize the reader with the gradual evolution and growth of astronomy in the Indian subcontinent over the ages. Starting with the status of the subject in the hoary distant past, the reader is made aware of its gradual evolution over the centuries, its interaction with the astronomies of different parts of the world, finally leading to its present status. The reader is also made aware of the present status of our knowledge of astronomy and cosmology. In an appendix, the reader is also introduced to the basic essentials of Panchang, Horoscope, and Astrology.

For a proper appreciation of the subject matter presented in this book, it will be helpful if the reader is aware of the basics of observational astronomy. Keeping in view that some of the readers may not be very familiar with such basics, before embarking upon our voyage of tracing the evolution and development of astronomy in India over the ages, we present in the subsequent sections of this chapter the essential basics of observational astronomy.

4. Basics of Observational Astronomy

In this section we familiarize the readers with basic essentials of observational astronomy so that he/she can better appreciate the gradual evolution and growth of the knowledge of astronomy through ages which is being presented in the succeeding chapters of this book.

4.1 Celestial Sphere

When one looks up at the sky, it appears a hemispherical dome with the sky forming the spherical surface on which the heavenly bodies such as the sun, the moon and the stars seem to be studded. It is bounded below by the surface of earth. The earth appears to meet the sky in a great circle which we call horizon. The observer is at the centre of this hemisphere. In astronomy this hemispherical surface is called the celestial sphere. It is of interest to note that celestial sphere is not unique. It is with respect to the observer. It varies from observer to observer depending upon his location on earth. To a cursory observer, the sun, the moon and the stars all appear to be lying on its surface, and so at the same distance from the observer. However in reality that is not so. The sun, the moon and the stars are not all at the same distance from the observer. They appear so because of their large distances from the observer. The situation may be compared to the distant trees near the horizon. They all appear to be at the same distance from the observer on the circular arc of horizon, whereas in reality that is not so.

In fact what one sees as the spherical surface of the sky is in reality the spherical surface formed by the distance up to which one can see in different directions. Distances of the sun, the moon and the stars are not the same. Moon is nearest to us, next comes the sun and then the stars. Moreover even all the stars are not at the same distance. The fact that the stars are farther from us than the sun and the moon becomes clear when sometimes it is noticed that a particular star is gradually approaching the disc of the sun or moon, it then disappears and after sometime reappears on the other side of the disc of sun or moon. During its crossing the disc, it is not visible on the disc. So it must have gone behind the disc and so must be at a greater distance. Moreover the fact that the apparent sizes of the sun and moon are bigger than the stars further strengthens this conclusion as the observed size of an object not only depends upon its actual size but also on its distance from the observer. Same object starts appearing smaller and smaller as it moves farther and farther away from the observer.

4.2 Important Points and Circles on the Celestial Sphere

The celestial sphere has observer O as its centre. The bounding great circle below which the observer can not see is called horizon. Horizon has four cardinal points on it namely North (N), East (E), South (S) and West (W), each 90º apart. Sun and stars rise in the eastern part of horizon (NES) and after moving across the sky they set in the western part of the horizon (NWS). The paths of the stars in the sky from the eastern horizon to the western horizon are called their diurnal paths. These are parallel small circles. Each star traverses the same identical path each night.

The highest point of the celestial sphere (which is vertically above the observer) is called Zenith (Z)). Every great circle arc drawn from Z crosses the horizon at a right angle. The great circle arc EZW that passes through zenith and the east and the west points of the horizon is called prime vertical. The great circle arc NZS which passes through zenith and north and south points of the horizon is called prime meridian (or simply meridian). A star (as well as the sun and the moon) is at its highest position in the sky when it is crossing meridian during its diurnal motion. At that stage it is said to be in transit.

It is noticed that the parallel small circles which are diurnal paths of stars do not have OZ as their axes of rotation (a circle drawn on the surface of a sphere is called a great circle if its centre is same as the centre of the sphere else a small circle). Their axis of rotation is OP which is inclined to OZ at an angle that depends upon the position of the observer on earth. In fact angle POZ is same as the latitude of the observer O on earth (it is usually denoted by φ).

It is also noticed that certain stars which are close to P in the sky never rise or set because their diurnal paths never go below the horizon. Such stars are called circumpolar stars. For a star to be a circumpolar star, PX must be less than PN. (In the figure X2 is a circumpolar star but X1 is not). In fact since OP is parallel to the axis of rotation of the earth, a star which is exactly at P will not take part in diurnal motion and will always remain fixed. In fact there is a star very close to P but not exactly at P. This star is called Pole star.

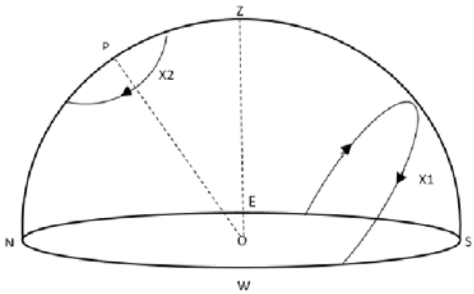


Fig.1

Two other great circles which play important roles in the observational astronomy are Equator and Ecliptic. Equator is a great circle which is perpendicular to OP so that its plane is parallel to the plane of earth's equator (diurnal paths of the stars are small circles parallel to this great circle). Ecliptic is the path which is traced out by the sun in the sky amongst the stars during the course of an year (because of the annual revolution of the earth around the sun).

Path traced out by the moon on account of its revolution around the earth which it completes in about a month (from one new moon (full moon) to the next new moon (full moon)) is also a great circle on the celestial sphere. However where as the positions of great circles equator and ecliptic are fixed on the celestial sphere of the observer and do not change with time, it is not so in the case of the orbit of the moon. Orbit of the moon on the celestial sphere changes its position from month to month and year to year.

Any two great circles which are drawn on the surface of a sphere cross each other at two points called Nodes. These two points are diametrically opposite 180 degrees apart. The points where the equator and the ecliptic cross each other are called its ascending and descending nodes. Ascending node is the point on crossing which the sun enters the northern hemisphere above the equator. This point is close to the first star in the group of stars called Aries. That is why it is also called the first point of Aries, and is symbolically denoted by (ɣ-Gamma). Descending node is the point on the ecliptic on crossing which the sun enters the southern hemisphere. This is close to star Libra and is so called Libra. Sun is at the first point of Aries on 21st March and at Libra on 23rd September. On these two days the sun shines vertically on the equator and the days and nights are equal (each of 12 hours duration) in the entire world. From 21st March to 23rd September days are longer in the northern hemisphere and shorter in the southern hemisphere. The reverse is the case from 23rd September to next 21st March when days are longer in the southern hemisphere and shorter in the northern hemisphere. In fact mid way on June 21, days are the longest in the northern hemisphere and on 22nd December, the days are shortest in the northern hemisphere. The point on the ecliptic where sun is on 21st June is called summer solstice and the point on the ecliptic where the Sun is on 22nd December is called winter solstice. These two points are on the ecliptic 90º each from Gamma and Libra on the opposite sides.

4.3 Difference between a Star and a Planet

Sun radiates huge amounts of energy in the form of heat and light. It shines by the light that it radiates. Moon also shines at night. However it does not shine by its own light. It shines by reflecting back the light of the sun that falls on it. The part of the moon facing the sun shines. The other half on its back is dark. That is why the light of moon is mild and soothing and not intense and hot like that of the sun.

It is not only the moon that shines by reflecting the light of the sun. There are some other heavenly objects also which shine by reflecting the light of the sun. These are called planets. In fact these are satellites of the sun like our earth. Like our earth these are also orbiting around the sun. These are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Neptune and Pluto in that order in terms of their distances from the sun, (Ancients were not aware of Neptune and Pluto because of their very large distances from the earth). To an observer on earth these planets appear specs of light like other stars. It is so because of their great distances from the observer on earth compared to their sizes.

A question that naturally arises is: How to distinguish a planet from a star? There are some simple ways in which even a common observer can distinguish a planet from a star. One of these is that where as the light from a star flickers, the light from a planet does not flicker. Light of a planet is steady. Moreover the planets being members of the solar family are located in the sky near the ecliptic. (One should not expect a bright star near the north pole that appears to be emitting steady light to be a planet.) Another distinguishing test which is possible with the help of a reasonably powerful binocular is that when looked through a reasonably powerful binocular, a planet appears as a disc where as a star still appears a flickering dot of light. Again when viewed over long periods of time, a planet changes its position relative to the neighboring stars (because like our earth it is also revolving around the sun), however a star normally does not.

A question that naturally arises in the mind is that what are these stars after all? In fact stars are like our sun radiating their own energy. Most of these are as big as our sun. (In fact many are even much bigger than our sun). They appear specs of light because of their very large distances from the observer. The brightness of an object depends upon its intrinsic brightness as well as its distance from the observer. The same bright object appears dimmer when it is seen from a larger distance (in fact the brightness of an object varies inversely as the square of its distance from the observer). The fact that the stars appear as specs of light implies that these are very far off from us. Moreover all the stars have neither the same intrinsic brightness nor are all at the same distance from the observer. The nearest star (after the sun) is Proxima Centauri. It is more than four light years away from us. (Light year is the distance travelled by the light in one year travelling with the speed of 186000 miles per second!) Light from sun reaches us in about 8 minutes. In fact the light that we are just now receiving from the star Proxima Centauri started from it more than 4 years earlier. If any change has happened to it in the last four years, we shall come to know of it only later. There are stars even millions of light years away from the observer! So what we see around us in the sky is a picture of the universe not at the same epoch of time. In fact the farther an observed object is, farther back in time we are viewing it.

Not only the distances of the stars differ, their brightness also differs. The brightest visible star in the sky (after sun, moon and venus) is Sirius. Sun which appears to us very bright would not appear as bright as even Sirius when viewed from the same distance as the nearest star Proxima Centauri. Sirius is much farther away than even Proxima Centauri. So in reality our sun is not even as bright as Sirius and the scientists are now aware of stars which are even much brighter than Sirius. These stars appear dim because of their large distances.

4.4 Paths of the Sun and the Moon in the Sky

Paths of the sun as well as the moon in the sky relative to other stars when marked on a celestial sphere are great circles which are inclined to each other at a small angle of around 5º. However whereas the path of the sun on the celestial sphere (called Ecliptic) is fixed and does not change with the passage of time, it is not so in the case of the path of the moon. Had the path of the moon in the sky been also fixed, then if in a particular year or a month moon moves across a star (say Chitra) just grazing it, then it would have been doing so each month and each year. However, that is not so. Moon's path in the sky relative to the neighboring stars keeps on shifting from month to month and year to year.

4.4.1 Plotting the path of the Moon on the Celestial Sphere

It is a bit difficult to locate the exact path of the moon on the celestial sphere visa-vis the other stars. This in fact changes from month to month and year to year. Difficulty arises on the following accounts:(i) On a full moon night only very bright stars are visible in the sky. (ii) It is difficult to decide as to when exactly moon becomes full. (In fact for a few days prior to the full moon and for a few days after the full moon, there is hardly any perceptible visible change in its shape. Therefore it is not easy to decide as to when exactly the full moon occurs.)(iii) Another complicating factor is that after 12 lunar months, the moon is not close to the stars to which it was close twelve months earlier.

The main reason behind all these complicating factors is the fact that a lunar month is not of exact 30 or 29 days. It is around 29 and a half days. As a result, 12 lunar months of 29 and a half days yield around 354 days which is not same as the number of days (365 and a quarter) in a solar year (the duration in which earth makes one complete revolution of the sun or relatively sun makes one complete revolution around the earth). As a result, a lunar year of 12 months is around eleven and a quarter day shorter than a solar year.

4.4.2 Plotting the path of the Sun on the Celestial Sphere

Compared to plotting the path of the moon, plotting the path of the sun on celestial sphere amidst neighboring stars is still more difficult. Unlike the path of moon, the path of the sun amongst the stars does not change from month to month or year to year and is fixed. However difficulty arises because after sun rise, the stars are not visible in the sky. So it is not easy to plot the path of the sun amongst the stars. (It is not that the stars are not their during day time. They are there but not visible because of their very low brightness compared to intense brightness of the sun). Sun's path in the sky relative to the stars is usually plotted by observing the positions of stars close to the sun immediately before it rises and immediately after it sets.

Solar orbit (called the ecliptic) as well as the lunar orbit, both divide the celestial sphere into two equal halves and are inclined to each other at a small angle of around 5º. As a consequence for about fifteen days in a month, the moon is above the ecliptic and for about the next fifteen days it is below the ecliptic.

4.5. Waxing and Waning of the Moon

Moon is observed to gradually increase in size from just a crescent to a full moon in about fifteen days (called waxing moon) and then gradually diminish in size from full moon to crescent in the next fortnight (called waning moon). The physical reasons behind this natural observed phenomena are as under.

As mentioned earlier, our earth is revolving around the sun taking along with it the moon. Moon is in fact a satellite of the earth. It is rotating about its axis as well as revolving around the earth. It completes one revolution around the earth in one lunar month. Its periods of rotation and revolution are exactly the same.(That is why we always see the same face of the moon. Its back is not visible from earth). One half of the moon which faces the sun is always bright and the other half dark. However an observer on earth does not always face the same side of the moon. It is full moon when he is viewing its complete bright half. And it is new moon when he is facing its complete dark half. In between the two, he faces its gradually changing partly bright and partly dark parts. This is the physical cause of the waxing and waning of the moon.

4. 6. Eclipses

The points where the orbits of the sun and the moon cross each other on the celestial sphere are called 'Paats'. In Hindu astronomy these are named Rahu and Ketu. Since the orbit of the moon is not fixed on the celestial sphere and keeps on shifting from month to month, the positions of Rahu and Ketu are not fixed on the celestial sphere. These two points have however a special significance because the eclipse of sun or moon can only happen if moon is in the vicinity of one of these two on a new moon or a full moon day. A lunar eclipse is possible if this happens on a full moon day and a solar eclipse is possible if it happens on a new moon day.

Whereas an eclipse of the moon occurs if on a full moon day, the shadow of the earth falls on the moon, the eclipse of the sun occurs only if on a new moon day, the moon comes directly between the sun and the earth. As the orbit of the moon is inclined to the ecliptic, normally on a new moon day or a full moon day, all the three are not exactly in the same plane and same direction. As a result an eclipse does not take place every new moon and every full moon day. When moon is near Rahu or Ketu, the earth, the sun and the moon are almost in alignment in the same plane. As a result depending upon their relative positions on such an occasion, there can be a full or partial eclipse of the moon on a full moon day and full or partial (and sometimes even annular) eclipse of the sun on a new moon day. An eclipse may be visible in some parts of the world and not in others. It may be also only partial at some places and full at others.

That is perhaps why in Hindu mythology, Rahu and Ketu have been called demons (Rakshsas). It is claimed that an eclipse occurs when one of these two Rakshsas devours the sun or the moon. People are advised to do penance in the form of bathing in holy rivers and giving liberal alms to the poor and needy to appease these demons so that they may liberate the captive sun or moon.

4.7. Specifying the position of a heavenly body on the celestial sphere

In order to understand and analyze the observed behavior of a heavenly body with respect to its neighbors, it is necessary that the positions of the heavenly objects on the celestial sphere be assigned suitable position coordinates. For this help is taken of a technique that is used to assign position coordinates to points on a plane surface.

Points on a plane surface are assigned position coordinates by drawing two mutually perpendicular straight lines X'OX, Y'OY (called axes) that cross each other at right angle at point O (called the origin)

To assign coordinates to a point P in the plane, we draw PL perpendicular from P on X axis and measure distances OL and LP. Let these be x and y respectively. Then point P is assigned the coordinates (x,y). (If P is to the left of YOY,' then its x coordinate

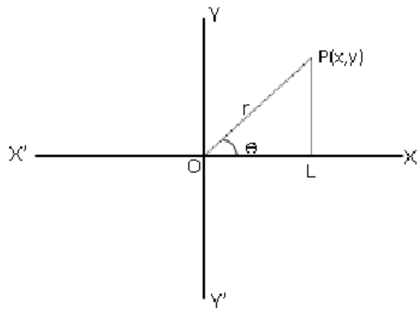


Fig.2

is taken negative and if P is below XOX', its y coordinate is taken negative). Given (x,y) the position of point P is uniquely fixed in the plane. (x,y) are called the cartesian coordinates of P. An alternative way is to join OP and measure its length r and angle θ which it makes with OX. Then (r,θ) can also be used to specify P (These are called its polar coordinates).

In the case of points on the surface of a sphere, we generally choose one great circle (say OL with centre at C) on its surface as the reference circle (corresponding to x axis) and some fixed point (say O) on this great circle as reference origin (corresponding to origin O of XOY plane). In order to specify location of a point lying on the surface of this sphere, we draw great circle arc XL perpendicular from X on the great circle OL. Then arc lengths $\overset{\frown}{OL}$ and $\overset{\frown}{LX}$ specify position of P on the sphere. If r is the radius of the sphere and the arcs $\overset{\frown}{OL}$ and $\overset{\frown}{OX}$ subtend angles θ and ϕ respectively at its centre C, then

$$\overset{\frown}{OL} = r\theta \text{ and } \overset{\frown}{OX}=r\varphi, (\theta,\varphi) \text{ being measured in radians).}$$

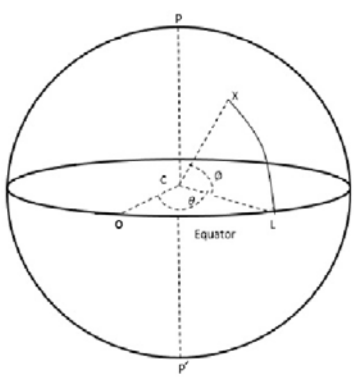


Fig.3

Since r is common to $\overset{\frown}{OL}$ and $\overset{\frown}{OX}$, position of X is uniquely specified by just specifying angles θ and ϕ respectively. (θ , ϕ correspond to x,y coordinates in a plane.) In fact a diameter of the sphere passing through its centre C and perpendicular to the plane of the great circle COL is called its axis. It crosses the surface of the sphere at two points P and P' called the poles of the great circle COL. (Great circle arc through every point X of the sphere perpendicular to plane COL will pass through P and P'.)

As the surface of the earth as well as the surface of celestial sphere are both spherical surfaces, this very approach is used to specify the location of points on earth as well as the celestial sphere.

4.7.1 Specifying Location of a Point on the Surface of Earth

In the case of points on the surface of the earth, the great circle which is chosen as the reference circle is equator. (This is a great circle at right angles to the axis of rotation of the earth). The origin of reference chosen on this great circle (equator) is the point O on it where great circle arc through the north pole, the south pole and Greenwich observatory located in U.K crosses the equator.

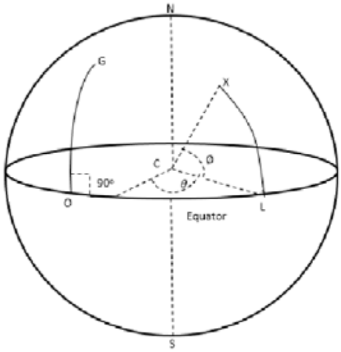


Fig.4

In the case of a point X on the earth's surface, if XL is the arc of great circle perpendicular to great circle COL, then the angular measure θ of arc OL is called its longitude and angular measure ϕ of arc XL its latitude.

The longitude of a place on earth can vary from 0 to180º east or 0 to180º west depending upon whether the place is to the East or West of Greenwich. In fact 180º E and 180º West are identical. This great circle arc is called 'date line'.

In order to ensure uniformity in time keeping throughout the globe, the ships and aero planes crossing this line from West to East have to put ahead their date by one and those crossing it from East to West have to set their date back by one. (Most of the date line passes through sea. Where ever it crosses an island, the entire island has been put on one side of the date line). Latitude of a place on earth can vary from 0 to 90º north or 0 to 90º south. Points on equator have zero latitude. Whereas points in the northern hemisphere of earth have north latitudes, those in southern hemisphere have south latitudes.

4.7.2 Specifying the Position of a star on the Celestial Sphere

Approach similar to the one used for specifying the position of a point on the surface of the earth is used for specifying the position of a heavenly object on the celestial sphere. However, depending upon requirements, three different reference circles are used. This has lead to three systems of co-ordinates for fixing the positions of points on the celestial sphere. We discuss these briefly one by one.

(i) Azimuth and Altitude

In this case, the great circle chosen as the reference circle is horizon and the North point on it as the reference origin. If L is the foot of the great circle arc drawn from X on the horizon, then the angular measure of the great circle arc NWL is called its azimuth and angular measure of arc XL its altitude. Azimuth can take values from 0 to 180º (or 0 to 12 hours) east, if L is to the east of north and 0 to 180º (0 to 12 hours) west, if L is to the west of north. Altitude can have any value from 0 to 90º (sky below horizon is not visible). Angular measure of arc ZX is called the Zenith distance. (Zenith distance is 90 minus altitude).

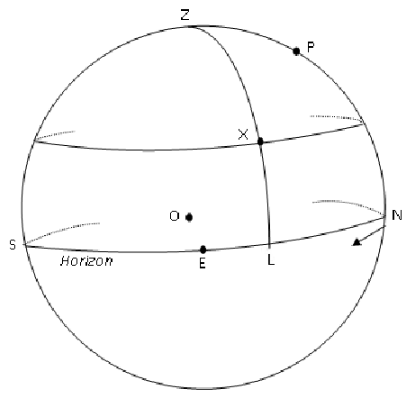


Fig.5

Angle XZN is called the hour angle (usually measured positive through the east). This system of coordinates is useful in analyzing problems arising out of daily rotation of the earth about its axis, such as the times of rising and setting of the sun, the moon, the planets and the stars; duration of day light at a given place on a given day etc.

(ii) Right Ascension and Declination

In this system, the reference great circle is celestial equator and the point chosen on it as origin is ɣ, the first point of Aries where ecliptic crosses equator. Angular measure of arc length ɣL is the right ascension and angular measure of arc length XL the declination of X.

Right ascension and declination are usually denoted by (α,δ). R.A can vary from 0 to 360° or (0 to 24 hours) and declination from (0 to 90º north if X is above the celestial equator towards north pole, and 0 to 90º south if X is below the equator). An important property of this system of coordinates is that where as Azimuth and Altitude of a star change with time, the right ascension and the declination coordinates of a star are fixed once for all and do not change from hour to hour or day to day and even year to year because the position of the celestial equator (the reference circle in the present case) and the origin (where it crosses ecliptic) do not change because of diurnal (daily) rotation of earth about its axis

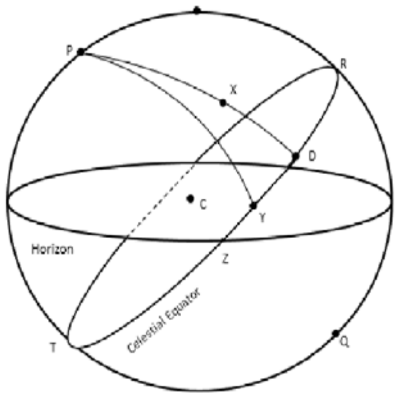


Fig.6

This system of coordinates is useful in analyzing problems related to the relative locations of stars in the sky.

(iii) Longitude and Latitude

This system of coordinates is similar to the right ascension and declination coordinate system except that the reference great circle is now ecliptic and not the equator. Origin is again ɣ, the first point of Aries. Longitude and latitude of a point on the celestial sphere are denoted by (λ, β). This system of coordinates is useful for analyzing the problems related to the ecliptic, the sun, the moon and the planets of the solar system. (In all these cases whereas λ can vary from 0 to 360º, β is usually small (positive or negative).

We have techniques for transforming from one system of coordinates to another so that whenever a necessity arises, knowing the coordinates for a point on the celestial sphere in one system of coordinates, these can be transformed to obtain its coordinates in the desired system.

4.8. Precession and Nutation

We have seen that ɣ (the first point of Aries) and Libra are the points of intersection of the great circles equator and ecliptic. Where as equator is reference circle for right ascension and declination (α,δ) coordinates, ecliptic is the reference circle for longitude and latitude (λ,β) system of coordinates. In both these cases origin of reference is ɣ, their point of intersection. Unfortunately the position of ɣ, the first point of Aries (where these two great circles cross each other) is not fixed. It is slowly receding backward along the ecliptic making one complete revolution of the ecliptic in around 26000 solar years. This is due to the fact that the direction of the axis of rotation of earth is not fixed in space. It is making a small circle (like the axis of rotation of a spinning top). This phenomena of the slow backward motion of ɣ along the ecliptic is called precession. It causes the coordinates of stars in the sky to slowly change with time. Moreover this backward motion of ɣ along ecliptic is not at a uniform. Deviation from its mean average value is called nutation.

If the position coordinates of some star in a historical document of the distant part are mentioned, then comparing these with their present observed coordinates, one can estimate how far back in time the earlier observations were made and thus estimate the likely date of that historical document. This technique has in fact been used in certain cases to assign dates to the historical documents of the past.

5. Some Well known Stars and Stellar Constellations

If one looks up at the sky at night, particularly on a dark night, one finds it studded with stars of varying brightness. Some are very bright and some so dim that these are hardly visible to the naked eye. Moreover many of the stars appear to be clustered in groups called stellar constellations. Many of such well known clusters have been given specific names. In this section we mention in brief some of the well known stars and star clusters.

Pole Star: This is one of the most well known stars. It is located very close to the north pole of the celestial sphere. As a result it hardly takes part in the diurnal motion and is therefore for all intents and purposes regarded a fixed star. However this star is not a very bright star. It has been guiding travelers in the past, particularly at night. Sailors in the seas and caravans in deserts have been using it to fix their ordinal directions as it gives the direction of the north. In view of its practically fixed location very close to the north pole, at places in the northern hemisphere, it never goes below the horizon. As a result, it neither rises nor sets there. There is also a ritual in Hindu marriages according to which the first act which a newly married couple is asked to perform is to gaze at the pole star. (Implying there by that in their marriage they will remain as steadfast as the pole star.)

Great Bear and Seven Sisters: These are all circumpolar stars close to the north pole. These consist of Ursa major, Ursa minor, Cassiopea and Dreco. Two of these form the outer wall of the bowl shape formed by them. The brightest star in Ursa major is the Polar star. Cassiopea is on the other side of the north pole from Ursa major. It is almost directly opposite the Big-dipper. This group of stars is named Cassiopea as in shape it resembles the crown of a past Egyptian queen named Cassiopea. Star next to Cassiopea is named Cephius (name of the husband of Cassiopea).

Draco the dragon: This is an another famous stellar constellation located near the north pole beneath Ursa major. Its shape is like dragon which Hercules faced.

Orion and its bright stars: Orion stellar constellation is next to the Big-dipper. It is one of the most well known stellar constellations. Its shape and its bright stars dominate the winter night sky in northern hemisphere. In shape it resembles the giant Orion with a bull in its other hand about to charge.

Capella is a group of seven twinkling stars forming a semicircle. It is also called the northern crown.

Sagittarius is a group of stars shaped like a tea pot. It is located close to the milky-way.

Hercules Constellation is shaped like Hercules holding a bow in his out stretched arm. It is located north of Scorpian.

Pisces is a well known star located below the celestial equator in the southern sky still lower than Antares. It is a lonely star seen shining brightly.

Andromeda and Peagasus are two different stellar constellations joined by one star at the corner of square formed by Peagasus.

Paelieds This cluster of stars is located in the interstellar dust cloud in the direction of Tarus, the bull.

Spica It is the 15th brightest visible star in the night sky. It rises a little south of the exact eastern point in the sky.

Vega This star appears around 3 hours after the star Arcturus in the north eastern horizon. It is bluish white in colour.

Anatares is a star which lies south of the celestial equator.

Some stars and star groups are not visible through out the year. Moreover some of the stars close to the south pole of the celestial sphere are never visible from the northern latitudes. Similarly many of the stars and star groups close to the north pole are not visible from places located in the southern hemisphere.

6. Terms Specific to Hindu Astronomy

The terminology used thus far is common to most of the astronomies of the world. However the terminology being introduced next is primarily related to Hindu astronomy and astrology.

Rahu Kal: Rahu Kal is a period of time each day which in Indian astrology is considered inauspicious for starting any new work of importance. It is generally one eighth of the time between the sunrise and the sunset. Taking duration of sunshine period to be 12 hours (6 A.M. to 6 P.M), it is about one and half hour each day. However it falls at different times on different days of the week. It is from 7.30 A.M to 9A.M on Mondays, 3 P.M to 4.30 P.M on Tuesdays, 12 noon to 1.30 P.M on Wednesdays, 1.30 P.M to 3.00 P.M on Thursdays, 10.30 A.M to 12 noon on Fridays, 9 A.M to 10.30 A.M on Saturdays and 4.30 P.M to 6.30 P.M on Sundays. Due to variation in local and standard times, this is in fact slightly different from the above durations from place to place.

There is Rahu Kaal in night also. However that is not given much prominence since most of the activities in the past were undertaken during day time. Two other periods of the day which are also considered some what inauspicious are called Visha Ghati and Yama Ghantam.

Nakshatras: These are essentially the division of the ecliptic into 27 equal parts. These are 27 in number. Their names are: Ashvni, Bharni, Kritika, Rohini, Mrigashirsha, Adra, Punarvasu, Pushya, Ashiesha, Magha, Purva Phalguni, Hasta, Chitra, Swati, Vishakha, Anurasha, Jyeshtha, Mula, Purva Ashadha, Uttara Ashasha, Abhijit, Sravna, Dhanishta, Shatabhisha, Purva Bhadrapada, Uttra Bhadrapada, and Revati.

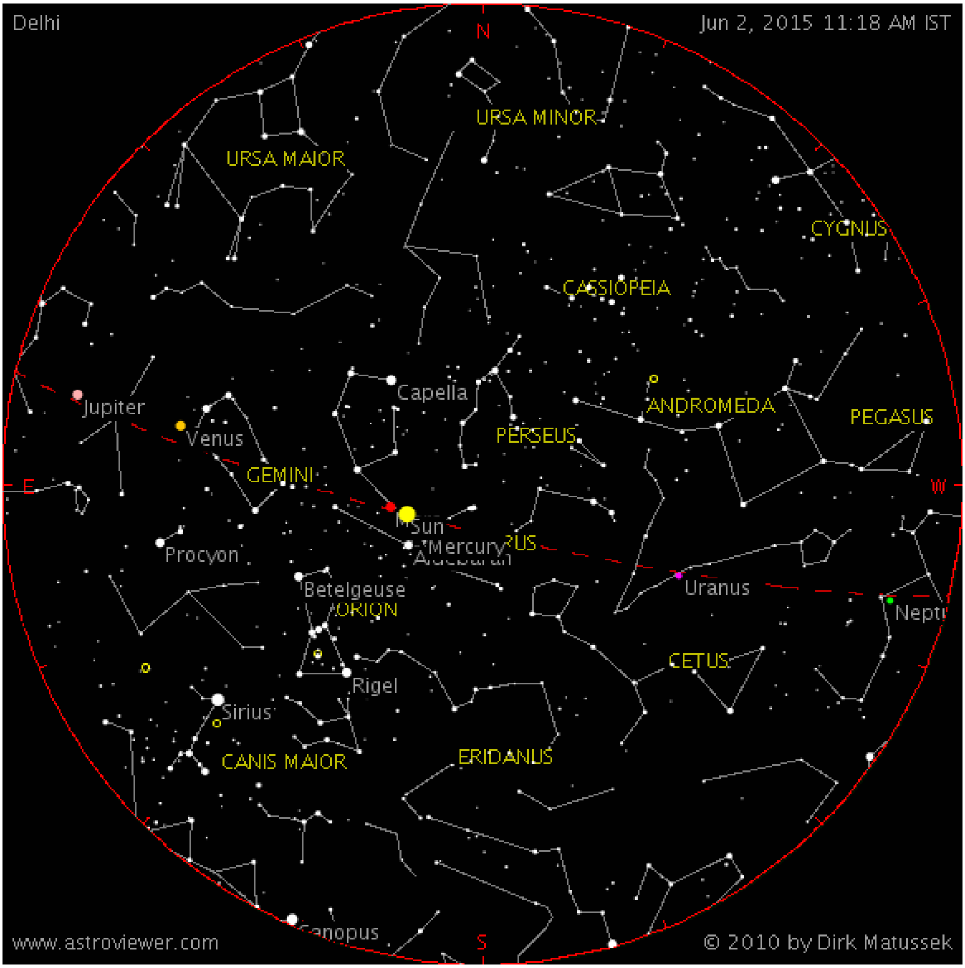
Padas (Quarters): Each of the twenty seven nakshatra covers 13º, 20' of the ecliptic. Each nakshatra is again divided into quarters or four equal padas. Twenty seven nakshatras, each with 4 padas, give a total of 108 padas which is the number of beads in a mala (rosary) indicating all the elements (ansh) of Vishnu.

Rashis: These are twelve in number, namely: Mesha (Aries), Vrishabha (Taurus), Mithuna (Gemini), Karka (Cancer), Simha (Leo), Kanya (Virgo), Tula (Libra), Vrishchika (Scorpio), Dhanu (Sagittaurs), Makra (Capricon), Kumbha (Aquarius), and Meena(Pisecs).

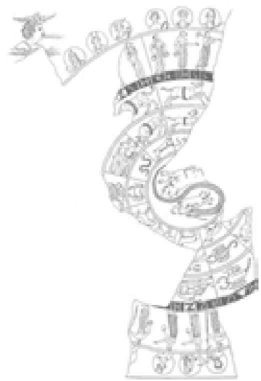
Sun moves through the circle of 12 Rashis in an year, taking about a month to pass through each one of these Rashis.

7. View of The Night Sky

We present here a view of the night sky of New Delhi (India) on June 2,2015 (copied from internet).This will enable the reader to form an idea of the general appearance of the sky at night.



Night sky at New Delhi (India) on June 2,2015



02

PREHISTORIC ERA

The earliest known books of Indian literature are Vedas. These are four in number namely: Rig Veda, Sam Veda, Yajur Veda and Atharv Veda. These are not only the earliest known books of Indian Hindu civilization but perhaps even of the entire human civilization. Of these four, Rig Veda is the oldest. There are references to astronomy related topics in Rig Veda. This clearly indicates that astronomy had its roots in India even much earlier than the Vedic period.

There is a difference of opinion about the time period of Vedas. In the nineteenth century orientalist Max Muler referring to the word 'Arya' (noble, lofty) in Rig Veda formed the notion of an ancient Aryan race that had its origin in central Asia which gradually spread to India towards the east and Europe in the west. According to him Aryans entered India from north-west around 1200 B.C and after coming to the north-western part of India (most of which is now in Pakistan) they composed Vedas.

However in 1873 Archaeologists uncovered traces of an ancient well organized civilization along the banks of Indus and Saraswati rivers. These sites are scattered across modern day India, Pakistan and Afghanistan. Max- Muler assumes that invading Aryans replaced original Harapan culture with the new Aryan culture. However several evidences show that this is not a correct theory and the so called Harrapan culture is same as the Aryan culture and the Aryans in fact have been living in this part of India from distant past. This is supported by the fact that certain seals found during excavation of Harrapan sites show meditating figures in Yogic postures which might be of Shiva (The Hindu God of Himalayas). There is more evidence to support it.

There is mention of the river Saraswati in Rig Veda, the oldest of the four Vedas. Saraswati was an essential part of the Vedic civilization since its earliest days. Glacial melts of Himalays fed the river Saraswati. Around 8,000 BCE, the flow of this glacial water was so great that the river Saraswati flowed right to the Arabian sea. However after a couple of thousand years, its flow gradually decreased and it did not flow right up to the Arabian Sea. In fact around 2000 BCE the river dried up. This time line correlates with Harrapan villages being abandoned around 1,900 BCE. This provides the latest possible date for the compositin of Rig Veda. Had it been composed any time later than 2000 BCE, the mighty river Saraswati must not have been mentioned.

Whereas main Harrapan (Hari-apan) period is generally dated from 2,600 to 1900 BCE, locations of Mohenjedaro and Harrapan communities date as far back as 3,000 BCE. Seals have been found in Mohenjedaro with Swastika (ancient symbol of the Sun). The name comes from Sanskrit words Su (good) + asti (to be) + ka (adimunitive suffix)

In fact French Archeologist Jean- Francis while digging at the base of a pass through the hills of Baluchistan (now in Pakistan) at a location called Mehargarh along Bolang river, unearthed a city that had been continuously occupied from 6,800 BCE to around 2,000 BCE. In this city from the beginning, the dwellings were aligned with four cardinal directions (north, east, south and west). For the first thousand years, the corpses were buried with their heads towards the east and feet towards the west. Scholars are trying to decipher the scripts on the seals found from these locations and think it to be based on a Sanskrit type script. Some of these seals depict heavenly objects such as the sun, the moon and some stellar constellations.

These days more people believe that there was no invasion of India by the Aryans. India was their ancestral land where they evolved and grew culminating in the writing of Vedas. Even if it is accepted that the Aryans originally migrated to India from central Asia, then it must have happened in the very distant past (in fact much before the composition of Vedas as there is no mention of events related to central Asia in the Vedas). Hindus generally believe that North West part of British India comprising land to the west of Yamuna in the east and up to Kabul in the west, from Himalayas in the north to Arabian Sea in the south was the region where Aryans as a race originated and evolved. It was at a later stage that they spread to central Asia and Europe in the west and lands beyond Yamuna in India in the east. In fact there is no mention of Hindu's most sacred river Ganga in the early Vedic literature. Only rivers Saraswati and Saptsindhu (Indus river and its tributaries which include the five rivers of British period Punjab) find mention in it.

India's distant past before Vedic era is steeped in darkness. It is therefore difficult to say as to how much the Indians of the distant past were aware of the rudiments of astronomy. In fact basic knowledge of the rudiments of astronomy was to an extent primarily essential for the day to day working of a society that lived in helmets and villages and was dependent upon agriculture for subsistence. The prime driving force being the necessity to know in advance as to when to sow and when to reap a particular crop as well as the desirability of keeping a record of the passage of time. Another motivating factor must have been to use observed celestial phenomena to predict an individual`s future (a subject which we now call astrology). In fact since the distant past, the Sanskrit word for both observational astronomy and astrology has been the same and it is 'Jyotish'.

So it may not be out of place to assume that even before the advent of Vedic era, Indians were aware of the rudiments of astronomy. The earliest interest in astronomy must have been in observing periodic changes in seasons, waxing and waxing of the moon, eclipses, stellar constellations, times of rising and setting of different heavenly bodies, and later on constructing somewhat in-exact luni-solar calendars based on observations of the motions of the sun and the moon so as to be able to predict with reasonable accuracy the onset of various seasons which was essential for a predominantly agriculture based society. Fixing dates of different religious festivals must have been another motivating factor.

03

ASTRONOMY IN VEDIC ERA

India's distant past is steeped in darkness. As a result it is difficult to say as to how much the ancients were aware of astronomy. It is only in Vedas that one gets a feeling that the Indians of those times were aware of the basic rudiments of astronomy.

1. Vedas

Vedas are four in number: Rig Veda, Sam Veda, Yajur Veda and Athurv Veda. Of these Rig Veda is the oldest. Some times it is claimed that originally there were only the first three Vedas. The fourth Veda, namely Athurv Veda, is a later addition. That is why in ancient Indian literature, Vedas have been frequently referred to as 'Ved Triya' implying three Vedas. Amongst the first three, Rig Veda is in poetry form, Yajur Veda in prose form and Sam Veda in lyric form which can be sung. The fourth Veda, namely Athurv Veda, deals with matters such as peace, good conduct, penance and 'mantar tantar' etc.

Vedas have three main components: Sanhita, Brahmna and Aranyika (or Upnishads). Hindus do not consider Vedas to be the creation of human mind but the words of Almighty God. It is believed that the creator Brahma himself transmitted the knowledge contained in Vedas to humanity through spoken words. The rishis simply compiled these spoken words of Brahma into mantras contained in the Vedas. It is rishi Ved Vyas who eventually compiled the Vedas in their present form.

Study of Rig Veda shows that the Aryans at that time mostly lived in the Punjab province of British India, through which river Sindh and its tributaries flowed. They were spread over an area that extended from Yamuna in the east to Kabul (Kumbha of those days) to the west, and Himalayas in the north to river Narmada and the Arabian Sea in the South. Their prime vocation was raising cattle (cows in particular) and agriculture.

2. Astronomical References in Vedas

There are several astronomical references in Vedas. In Tritya Brahmana (30.11.01) the words sun, moon, planets, samvat (year), seasons, months, half months, arhotra (day and night), purnima (full moon) etc appear. It is also mentioned at one place in Rig Veda that an year has twelve months and each month is of 30 days. People also knew that the sun is one and it causes the day and night to happen and it is also the cause of the change in seasons. It was also known to them that there are six seasons in an year and each season is of two months (a month being the time period between two consecutive new (or full) moons). In Tritiya Sanhita (4.4.11) there is a mention of the names of the seasons as well as the months. According to it, spring season is of two months (Madhu and Madhav), and summer of two months(Shukra and Suchi). Next two months (Ish and Urja) are rainy season. Next season is autumn (sharad) of months (Ish and Urja). After this season comes winter (Hemant) season of two months (Sah and Shasya) and finally there is Sishir (Patjhar) season of two months (Taps and Tapasya).

It is mentioned in the Rig Veda that those days, an year was taken to be of 360 days. It was subdivided into 12 months each of 30 days. However since the solar year is of around 365 and a quarter days, each year there was a deficiency of 5 and a quarter days. In order to ensure that in the long run, the same seasons fall in the same months, in a period of around five years, two intercalary months were added to bring the lunar calendar in line with the solar year. However this resulted in an average length of 366 days per year which was a bit over correction. As a result the year still migrated four days every five years. In fact to ensure that the seasons keep pace with the months, Indian astronomers have been constantly tweaking and adjusting the calendars over the millennia.

In fact in order to ensure that the same seasons fall in the same months, there is a mention of thirteenth month in Vajsanya Sanhita. This additional month (called londh month) was added after few years of twelve months duration to ensure that the seasons kept pace with the months with which these were normally associated. Names of all the thirteen months appear in Tatriya Brahmna (3.10.1). These are: Arun, Arunraj, Pundrik, Vishvjit, Abhijit, Adraa, Pinvmann, Unnvaan, Rasvaan, Travaan, Sarvoshadh, Sambhar and Mahsvaan. It is mentioned in Aatriya Brahmna (7.17) also that the length of an year is 360 days. There is a stanza in Tanday Brahmna which mentions how to ensure accuracy in the number of days in an year (Tanday Brahmna 5.10.2). Its is mentioned there that in case extra days are left unadjusted, then the length of the year will gradually swell as waterman's 'mashkak' swells.

3. Nav Greha

In Vedic era, seven heavenly bodies were known to move faster than their neighbouring stars in the sky. These are Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn.People were also aware of the nodes of moon's orbit (where the moon's orbit crosses the sun's orbit). These were named as Rahu and Ketu. They were perhaps also aware of the nature of eclipses as well. It is mentioned that during an eclipse the moon is devoured by the demon Rahu/Ketu. The seven heavenly bodies mentioned above which move faster than their neighbouring stars in the sky, along with Rahu and Ketu, have been termed as Nav Greha (nine heavenly bodies). The Vedic names of these nine Grehas are:

Body	Sanskrit Name	Meaning
Sun	Aditya	Son of Aditi (the unchangeable)
Moon	Soma	Peace, Gentleness
Mercury	Buddha	Intellect
Venus	Shukra	Refined, Sensual
Mars	Ankgaraka	Burning coal
Jupiter	Brihaspati	Great (Brihat) protector (pati)
Saturn	Shani	Slow
Moon's North Node	Rahu	Dragon's Head
Moon's South Node	Ketu	Dragon's Tail

Hindu texts speak of Pravaha (celestial wind) as the force that moves these bodies.

People of Vedic era were perhaps also aware of the sun spots (black spots which appear occasionally on the surface of the Sun). In Rig Veda there is a mention of the revolving eye of the Sun (R.V.1.164.14). 'The Sun's eye keeps on revolving and on it depend all the worlds'. (It could also refer to Sun's orbit in the sky called ecliptic).

4. Amanant and Puranamant

Amanant and Puranamant are two alternative ways of keeping a count of the passage of time in months. In the case of Amanant the beginning of a new month is from new moon, while in Puranamant it is from full moon. From a common man`s view point Puranamant is more convenient as full moon is easy to identify. Amanant is roughly when the moon and the sun are in the same direction in the sky and so it is not convenient for a common person to identify this instant. However for astrological purposes, Amanant has been generally used. Even the extra month (Adhmas), when it is to be added in a particular year, is taken to start from the new moon day (Amanant).

According to Tratiya Sanhita (1.6.7) a month is supposed to end on a full moon day. However at another place (7.5.6.5) it is mentioned that where as some people consider a month to end on a full moon day, others consider it to end on a new moon day.

5. Why does the moon shine

Even during the period of 'Tratiya Sanhita' people were aware that the moon shines by the reflected light of the Sun. That is why it has been referred to as 'Surya Rashim' thereby (meaning an object which shines by the rays of the sun) (Tratiya Sanh. 3.4.7.1). Reason for Amavasia (New Moon day) has also been mentioned in Aatriya Brahmana (40.5). On a new moon day, the moon enters (Aditya) and becomes invisible and then repapers.

6. Names of the Days of the week

Names of the days of the week Sunday, Monday etc. are associated with the prominent heavenly bodies namely: Sun, Moon and five planets. These are considered to be of Indian origin. However there is no reference to the days of the week in Vedas, Brahamanas or

Sanhita literature. These are of some later date. In Vedic times the term 'Paksh' and its parts were more prevalent. Each lunar month was divided into two Pakshas: Shukul Paksh (waxing moon) and Krishna Paksh (waning moon). There is a mention of it at several places in Vedic literature. In Tatriya Brahamana (93.10.10.2) names of Pakshas have been mentioned as: Purva Paksha and Apurva Paksha. Sangyan, Vigyan, Darsha, Drishta have been mentioned as names of days in Purva Paksha and Prastut, Vshtut,Stut, and Asunvat as the names of days in 'Apurav Paksh'. Certain other names also appear at some other places in the Vedic literature.

Ancient history of Vedic period had devised a scheme to keep a record of the passage of the days in a lunar month. They referred to a lunar day as a 'tithi'. Fifteen tithis were assigned to the bright half of lunar month (Shukla Paksha, when the moon is waxing), and 15 tithis were assigned to the dark half of the lunar month (Krishna Paksha, when the moon is waning) making 30 tithis in a lunar month.

7. Names of the Parts of a day

At some places in Vedic literature there is a mention of the day time being divided into two parts called `Purvahand and Uprahand`. At some other places there is mention of day time being divided into four parts, each part being called a 'Prahar'. Names of four Prahars are: Purvhan, Madhyan, Uprahan and Sanyhan. At some places there is mention of a day being divided into fifteen parts, each part being called a 'Mahurat'. All these terms are in use in India even now. However their meanings have changed a bit. The word `Mahurat` is now used to denote the auspicious time for the start of an event or a function.

8. Tithi

In vedic literature the word Tithi has not been used in the same context as it is now used. In Aatriya Brahmna (32.10) it is defined as the time between setting of the moon and its next rising. However now it is used to denote the time taken by the moon to travel 12º relative to the sun (making 30 tithis in a lunat month). In Samvidhan Brahmna (216, 218, 313) words such as Shukul Panchmi, Krishna Panchmi, Shukul Chaturdashi, Krishna Chaturdashi etc. appear.

These days at times a tithi is skipped. However that was not so in Vedic times. There is no reference to a tithi being skipped in Vedic literature. However there is reference to Panchdash (fifteenth) tithi at some places. For instance in Tratiya Brahmna (1.5.10) moon is called 'Panchdash' as it waxes for fifteen days and then wanes for the next fifteen days. However there is no clear indication that tithis were in common used even during the times of Brahmanas.

9. Nakshatras

The word Nakshatra seems to have originated from the Rig Vedic Sanskrit words 'nak' meaning night and 'shatra' meaning altogether always, or from na (name of Moon) and kshetra (meaning place, mansion).Originally Nakshatras meant all visible stars in the sky. It is mentioned in Rikk Sanhita (1.50.2) and Aath Sanhita (13.2.17, 20.47.14) that with the appearance of all majestic Sun, Nakshatras and night disappear as a thief disappears with the appearance of day light. A stanza in Aath Sanhita (11.7) indicates that star clusters were also regarded as Nakshatras. However, gradually, the use of this term got restricted to only those bright stars which lie close to the path of moon in the sky. This is indicated in

Ritu Sanhita (10.85.2) and Aath Sanhita (14.1.2). In Tatriya Sanhita (4.4.10) names of all Nakashtras have been mentioned. These are: Kritika, Rohini, Mrigshirsh, Aadra, Panarvasu, Tishya, Ashlesha, Magha, Purav-Phalguni, Uttra-Phalguni, Hasta, Chitra, Swati, Indragni, Anuradha, Gyashtha, Do Vichitra, Shrona, Sreshtha, Satbhisk, Proshthpada, Ravati, Ashvyuj and Apbharni (twenty seven in all).

Moon completes a revolution relative to the near by stars in around 27 1/3 days. The integer nearest to it being twenty seven, 27 bright more or less equi-spaced stars near the orbit of moon were named Nakshatras. Mention of Nakshatra indicated the location of the moon in the sky amongst stars on a specific day. However 27 1/3 being greater than 27, some times even 28 Nakshatras have also been used. Gradually the word Nakshatra also started being used to indicate 1/27th part of the moon's (or Sun's) orbit in the sky.

Originally Hindus divided the orbit of moon in the sky into 28 more or less equal parts and called these Nakshatras. The names of these Nakshatras along with their associated principal stars are as under.

	Nakshatra	Associated Principal Star
1	Aswini	α Arietis, β Arietis
2	Bharni	Musca
3	Kritika	Alcyone
4	Rohni	Aldebaran
5	Mriga	λ Orionis
6	Ardra	α Orionis
7	Punarvasu	Pollux
8	Pushya	δ Cancri
9	Ashlesha	ε Hydra, α Cancri
10	Magha	Regulus
11	Purva-Phalguni	δ Leonis
12	Uttra-Phalguni	β Leonis
13	Hasta	ɣ Corvi, δ Corvi
14	Chitra	Spica
15	Swati	Arcturus
16	Visakha	α Lib, Librae
17	Anuradha	δ Scorpionis
18	Jyestha	Antares
19	Mula	λ Scorpionis
20	Purva-Shadha	δ Sagittarii
21	Uttra-Shadha	Sagittarii
22	Abhijit	Vega
23	Sravana	α Aquilae

24	Dhanishtha	ɑ Delphini
25	Satataraka	λ Aquarii
26	Pura- Bhadrapada	ɑ Pegasi
27	Ultra-Bhadrapada	ɣ Pegasi, ɑ Andromedae
28	Revati	Piscium

The sidereal lunar month (the time it takes the moon to return to the same position among the stars) is closer to 27 days than 28 days (about 27.322 days). At some point Hindu astronomers began skipping Abhijit nakshatra and started using 27 naxatras. Even now both 27 and 28 nakshatra systems are in use.

Each naxatra being 27th division of 360 is 360/27=13º,20'. Each naxtra has a principal star associated with it. Hindu astronomers of the past also used the 12-sign Zodiac. Using 12-sign Zodiac and 28/27 sign Nakshatra division helped them to trace celestial bodies under the time scales of both the Sun and the Moon.

In fact each naxatra has been further subdivided into four equal padas each being 3º,20'. (Pada in sanskrit means leg as in four legs of a quadruped animal or 'quarter' or 'quadrant'). The number of padas in the ecliptic divided into 27 naxatras yields 27x4=108 padas. This number is the number of beads in a 'prayer mala' of Hindus. This perhaps might have influenced dropping original count of 28 naxatras. The change could also have been because the 'draconic month' (during which the Moon's nodes revolve) is closer to 27 days (around 27.21 days).

10. Names of Months

Names of months in Tratiya Sanhita were Madhu, Madhav etc. However with the passage of time these names gradually faded out and were replaced by new names which were primarily based on associated stars. For example Chetra (or Chet) is related to star named Chitra. This is a bright star very close to the path of the sun in the sky. Similar is the case with new names of other months. There is some justification for this. Which month of the year is Madhu is not easy to tell. If this month was to repeat itself after every twelve months then it would not keep pace with the season with which it was originally associated (as happens in the Muslim calendar). The reason for this is that twelve lunar months constitute 354 days where as a solar year, according to which the seasons repeat, is of around 365 1/4 days. So each lunar year of 12 months has about 11 less days resulting in the loss of almost a month in three years. However Indian Rishis and Pundits were not comfortable with the months not keeping pace with seasons. The main reason for this is that India being essentially an agriculture based country, it would not have been easy for the farmers to know as to when to sow a particular crop. In order to ensure that the seasons keep pace with the months so that each year there would be same season in the same month, a way was discovered. It was noticed that on a full moon day, the position of the moon in the sky relative to the near by stars has definite relationship with seasons. So they started associating months with the stars. This resulted in months themselves being named with the names of associated stars. A sentence (Trat.BR.1.1.2.8) in Tratiya Brahman clearly indicates that the association of names of the months with related stars had started by then. It is stated there that when full moon happens near Pahguni star it means the beginning of a new year.

The path of the moon in the sky was divided into 27 more or less equal parts, each part being called a naxatra. Each naxatra was named after a bright star or a star cluster close to this part of the ecliptic. It appears that the new names of the months had not been fully formalized by the time period of Tatriya Grantha as there is no mention of these new names in it. However by that time it seems that a beginning had been made and it gradually evolved with earlier names being replaced by names of near by bright stars. For instance there is a mention in Amarkosh, Kalvarag 14, that the month in which full moon happens near Puspa naxatra is named Paush. Similar names of other eleven months have been mentioned there. According to Surya Siddhanta of later period, a month gets the name of the naxatra in which full moon of that month happens.

11. Eclipses

Eclipses have been mentioned in Vedic literature. However there is nothing there to suggest as to how far the real cause of eclipses was known at that time. At one place it is mentioned (Ri.Sa.5.40.9) that the Sun which was concealed in darkness by Sarvabhanu, the son of a Raksha, has been reclaimed by Atris who has this power which others do not have.

12. Planets

Planets are located near the path of the sun in the sky. These look like other stars but are relatively brighter. Moreover, whereas the light of a star flickers, the light of a planet does not flicker. It is therefore but natural that Rishis of the Vedic Era must have noticed them. Observations over a period of time must have also shown that these planets are not fixed like other stars but shift their positions relative to the near by stars. Anyone observing night sky over a period of time can not fail to notice them. Therefore it is but natural to expect some reference to these planets in Vedic literature.

Planet Brahaspati (Jupiter) finds mention in Tatriya Brahamana (3.1.1). It is mentioned there that planet Brahaspati when it first appeared was near the star Tishya (or Pushp). There is mention of planet Shukr also in Shatpath Brahmna (4.2.1). It is written there that Shukr and Manthi are his two eyes. The one that shines more is planet Shukr. It is called Shukr as it shines brightly. Moon is Manthi. In Tratiya Brahmana (1.2.5) there is mention of Brahaspati along with Shukr and Moon. The word Grah (Planet) appears in Aatharv Sanhita (19.9).

According to German Scholar Webber, the names of the planets must have originated from India itself because their present names are essentially Indian.

13. Mention of other Stars

Names of stars other than Naxatras also appear in Vedic literature. There is mention of Riksh (Sapt rishi) in Rik Sanhita (1.26.10). It is also mentioned in Shatpath Brahmana (2.1.2.4) that Saptrishi star cluster was earlier known as Riksh (Riksh means Bear (Bhalu)). In modern day western astronomy it is known as Ursa Major or Great Bear. There is mention of some other stars also.

It is thus apparent that the basic foundations of the observational astronomy were laid during Vedic Era itself. Months were based on the periodicity of the waxing and waning of the moon. A way had been found such that in the long run there was not much difference in the length of a solar year and twelve lunar months. This was being done by adding an additional month at suitable intervals so that in the long run same seasons fell in the same months. In fact in any year, the difference in the two was never allowed to exceed a fortnight. Full moon and new moon had great religious significance. In fact out of the five components of Vedas, one component is Astronomy. An ancient book on this component is still available.

14. Calendrical Awareness

Hymns of Rig Veda and Atharva Veda point to the observance of a lunar year. Moon was regarded as the maker of months. There are indications in Vedas which point to the fact that during that period people were aware of autumn equinox. There is also reference to Aditi (which corresponds to Pollux, longitude 113º), Daksha (Vega longitude 284º), Rudra (Betelguese longitude 86º) and Rohini (Aedebaran longitude 69º). The changed longitudes mentioned here are a consequence of the precession of equinoxes. These details are useful for another reason. They reveal the likely date of the composition of the scripture in which these are mentioned. Thus allowing for precession of around one degree every 72 years, the period should have been around 6200 B.C, 5400 B.C, 4350 B.C and 3070 B.C respectively. Hymn 1.164 of the Rig Veda composed by the sage Dirghatmas refers to a wheel of time with year of 360 lunar days and twelve lunar months. The year mentioned in the rhyme begins with the autumn of star Agni (Alcyon, longitude 59º5') corresponding to the year circe 2350 B.C. (By the way the numbering of the hymns also shows the use of decimal system.)

Yajur Veda and Atharv Veda reveal definite calendrical awareness. Many sacrifices including the Gavan Ayana, are of different lengths of time based on the daily cycle of the sun. For performing rituals, the day was divided into 3,4 or 15 equal parts, each with a specific name. Apart from naming 27 stars beginning with Kartika, Vedas mention five planets and the names of two of them, Jupiter (Brahaspati) and Venus (Vena). Tattriya Brahmna speaks highly of Nakshatra Vidya (knowledge of stars) and mentions some scholars of this science.

15. Time Period of Vedas

There are conflicting views regarding the time period of the Vedic Era. Where as orientalist Max Mullar regards it to be not earlier than 1200 B.C., other western scholars regard it to be around 2000 B.C. Hindus believe it to be even earlier than 4000 B.C. Bal Gangadhar Tilak in his book Orien, which is related to astronomy, puts forward an observational evidence recorded in Vedas to establish that the period of Vedas was around 4500 B.C. This view was later supported by Prof. Yakobi on the basis of his own independent computations.

Here we briefly consider the evidences in Vedas which help in identifying the era in which these might have been composed. A strong evidence which is used in this context is a statement in Shatpath Brahmna. It mentions that whereas Kritikain (Paelied star cluster) is always in the east, other stars are not in that direction. It is obvious that direction East refers to the point in the horizon where Paelied star cluster would have been rising. This fact was being used at that time to decide the correct direction for setting up of `yajuna kunds`. If one observes the eastern sky over a long period of time, then one observes that at the time of rising, each star first shifts its position in the horizon gradually to the north of east for about six thousand and five hundred years and then starts gradually shifting its position in the horizon towards south for the next six thousand and five hundred years. Thus after a star has risen exactly in the east point it will again rise in the exact east after around13,000 years. Looking at the position of Paelieds at present, one can therefore estimate as to when Paelieds must have been rising exactly in the East, and this must have been happening around 2,500 B.C.

Sometimes it is argued that the statement that Paelieds was rising exactly in the East might not be referring to the period in which Vedas were being composed but to some earlier epoch. However according to Dixit, it must be referring to the period of composition of Vedas as present and not past tense has been used. More over this is not the only evidence in support of the period of Vedas being around 2,500 B.C. There are some other corroborative evidences also. However before discussing these it will be appropriate to first consider the main objections against it.

According to Macdonal and Keath, one may not be justified in taking this statement at its face value as similar statements also appear in Bodhyan Shrot Sutra as well as. According to Barth another fact mentioned there was possible only in 6th century A.D. or even later. However the objections of Macdonell and Keath are not that serious. There are other astronomy related facts mentioned in Bodhyan Shrot Sutra which point to the fact that these must have been composed around 1300 B.C. and Shatpath Brahmna around 2500 B.C. Viternitis is of the view that the period of Shatpath Brahmna is around 1100 B.C. and not 2500 B.C.

Sometimes it is also argued that during Vedic Era, Hindu astronomers were not well equipped to make precise observations. This is substantiated by the fact that according to them an year was of 366 solar days where as actually it is around 365 and a quarter days. But this difference of 3 quarters of a day in the length of observed year from actual length of year in no way implies that they could not determine precise direction of the East in the horizon which is comparatively much simpler. It is mentioned in Kaushtiki Brahmana as to how the point of rising of the Sun in the eastern horizon first keeps on shifting slowly in the southern direction from day to day and then being stationary at its extreme southern position for a few days, it starts shifting back northwards. Based on these observations over a few years, one can determine the direction of exact East point in the horizon with reasonable accuracy.

In view of the above, there seems to be no justification in not accepting the conclusion that the period of Brahamana component of Vedas was around 2500 B.C. In Yajur Veda Sanhita as well as in Brahmanas wherever the stars are listed, the list always starts with Paelieds. There must have been some reason for it. Later period stellar catalogues start with star Ashwani. It appears that in each period the star lists started with a bright star nearest to the Sun at its time of rising on an equinox (when Sun is in the exact East and the duration of day time and night time is equal). This implies that in Vedic Era, the Paelieds were in east as the star catalogues of that period start with it, implying there by that the Vedic Era was around 2500 B.C.

Some other objections which are often raised by those who are not willing to accept that Paclieds star cluster was exactly in the east and that is why it headed stellar catalogues of that period are:

(i) It could have been just a convention as this cluster is easy to recognise.

(ii) If one is to accept the argument that Paelieds were being put at the head of stellar catalogues because these were in the East at that time, then it implies

> that the astronomers of that period were aware of the relationship between the Sun and the stars. However where as the relationship of stars with the moon is more apparent it is not so in the case of their relationship with the sun. In fact stars are related to both the sun and the moon and the astronomers of Vedic Era were aware of this relationship. This is corroborated by a technique mentioned in Tatriya Brahmana which was being used to determine relationship between the sun and stars.

Yakobi and Tilak have both argued in their works that in Brahmanas of Vedic Era, Paelieds were not being put arbitrarily at the top of the list of stellar catalogues of those periods but because this group of stars was in the exact East those days. Booler agrees with their argument.

Whitney and Thibo, both contend that even if one is to accept that the star catalogues of that period started with Paelieds because these were in the East those days, it still does not imply that these were in the exact East. These could be close to east. In Vedang Jyotish it is mentioned that the nights are shorter when the Sun is farthest North of East. It is mentioned that at that time Paelieds are 18 aansh away from East point in the horizon. Whitney and Thibo argue that this could have also been sufficient to justify putting Paelieds at head of stellar catalogues. In view of this the stellar catalogues with Paelieds at its head could have been of Vedang Jyotish Era and not Vedic Era. As will be discussed in the next chapter, the period of Vedang Jyotish is estimated to be around 1200 B.C. and according to Whitney and Thibo even this estimate can be in error up to one thousand years! So they argue that it is quite likely that Brahmanas are not as old as 2500 B.C. but could have been compiled around 800 to 600 B.C. However modern day calculations show that around 700 B.C. Paelieds were about 11 aansh from the exact east and not 18 aansh. It is therefore unlikely that for religious performances, the poles of Yajnas which were intended to be towards the East, were recommended to be set in the direction of Paelieds even though these stars were not in the exact east.

There are certain other evidences which point to the Vedic Era being even earlier than 2500 B.C.! For instance from Vedic times there is a ritual in Hindu marriages according to which the newly wed couple is asked to look up to the pole star in the North. This ritual is on account of the fact that from amongst all the stars in the sky, it is the only star which remains stead fast in its position in the sky where as other stars in the sky keep on changing their position in the sky from hour to hour on account of the diurnal motion of the earth as it rotates from west to east. This star is in fact at the point where the axis of rotation of the earth when extended outwards meets the sky. This point being on the axis of rotation of the earth does not take part in its rotion and remains fixed. The idea behind the performance of this ritual by the newly wedded couple is that the marital relationship of the newly wedded couple should be as steadfast as the pole star.

At present there is no bright star exactly at the North Pole of the celestial sphere. Obviously when this custom was first introduced in the Vedic Era, there must have been some bright star at the North Pole. Calculations show that around 2780 B.C, there was a reasonably bright star (Alpha Draconis) which was very close to the exact North Pole. Moreover not only that, in fact even for many thousand years before 2780 B.C. there was no such bright star close to North Pole. Even at present there is no bright star very close to the North Pole. However the custom persists. In fact the star near the North Pole towards which these days a newly married couple in India is made to look at is not a fixed star, but a star that makes a very small circle around the North Pole. This further supports the contention that Vedic Era was around 2500 B.C.

Some other references (such as auspicious times for embarking upon voyages) in Vedic literature have also been sometimes used to estimate the time period of Vedic Era and they also point it to be around 2500 B.C. But none of these is unambiguous and fool proof. Based on these and other similar arguments, where as scholars such as Weber, Yakobi, Booler, Barth, Viternitis, Pusin, Tilak,Dixit etc estimate the time period of Vedic Era to be anywhere between 2000 B.C. and 6000 B.C, scholars such as Whitnay, Oldenbergy, Thibbo, Keath, etc do not consider it to be that far back in time.

To sum up in case we accept that the Vedic literature which was originally being handed over from generation to generation through the word of mouth is a genuine record (and not based on hear-say facts) of what happened sometime in the distant past, then there is reasonable justification in accepting that the events of Vedic Era happened around 2500 B.C

04

VEDANG JYOTISH

1. Intoduction

Vedang means a component of Vedas. In view of its being considered a part of the Vedas, it was also regarded sacred and its reading and memorizing was regarded a virtue. That is why it escaped oblivion. However one may not perhaps be justified in calling it a book. It has just forty four shalokas. Therefore it may perhaps be more appropriate to regard it a booklet. The main reason behind its being so compact is the fact that in the distant past writing material was not freely available. As a result most of the information was generally composed in the form of easy to remember shalokas which were transmitted orally from one generation to the next.

Vedang Jyotish has two components. One component is Rigveda Jyotish and the other Yajurveda Jyotish. Both deal with more or less identical topics. Whereas Yajurveda Jyotish has forty four shalokas, Rigveda Jyotish has 36 shalokas. Although most of the shalokas in the two are common, they appear in these two in different orders. There are seven shalokas in Rigveda component which are not in the Yajurveda component. Again there are fourteen shalokas in Yajurveda component which are not in the Rigveda component. It is quite possible that both these booklets were compiled from some bigger work, which is now extinct. Most of the commentators subscribe to this view. However Dr. Shyama Shastri is of the view that the difference in the number of shalokas in Yajurveda is essentially on account of commentaries.

It is not easy to decipher the essence of shalokas in Vedang Jyotish as most of these are in a very terse and compact format. Certain shalokas which are essential for proper understanding of the meaning of shalokas in Vedang Jyotish seem to have been skipped. The reason might have been to make it easier for the user to memorize these for practical use. (The shalokas of Vedang Jyotish seem to have been designed for a specialist and not a novice).

2. Commentaries on Vedang Jyotish

There are several commentaries on Vedang Jyotish. These include the commentories by Somkar Webber, Sir William Jones, Whitney, Col Brook, Bently, Decks, Max-Muller, Thoba etc. Thoba`s commentary was published in 1879. Later on Krishna Shastri tried to explain the essence of those shalokas which earlier commentators could not comprehend properly. Later on Chotte Lal (pen name Brahaspati) in 1906, Sudhakar Dewadi in 1908 and Dr. Shyam Shastri in 1936 also published their interpretations of various shalokas of Vedang Jyotish. Eleventh shaloka which had been confusing experts was finally explained by Surya-pragyapti. Thus in a way all the shalokas of Vedang Jyotish are now fully explained and understood.

3. Yajurveda Vedang Jyotish

Of the 44 shaloka of Yajurveda Vedang Jyotish, the first four and the last four are not related to astronomy. The first shaloka is dedicated to lord Prajapati and the second to Kal (time). Third shaloka highlights the significance of Jyotish Shastra. In the fourth shaloka it is stated that amongst all Vedangs, Jyotish Vedang is the best. Last shaloka blesses the Jyotishi (Astronomer). It is mentioned that the scholar (pundit) who understands and appreciates the knowledge related to the motions of the sun, the moon and the stars is blessed with progeny and lives happily in this world and goes to the realms of moon, sun and stars after death. In fact out of the total of 44 shalokas, only 37 deal with matters related to Astronomy (Jyotish).

4. Concept of Yuga

According to Vedang Jyotish, there are three basic units for measuring the passage of time. These are (i) Ahrotra (day and night) (ii) Lunar month which is the duration from one full moon (new moon) to the next full moon (new moon) and (iii) Solar year which is the time for one complete revolution of earth around the sun (or relatively the sun around the earth). Relationship between these three units of measuring the passage of time has been a matter of investigation and study since the distant past. Where as the exact duration of Ahrotra is easy to measure, it is not so in the case of the lengths of a lunar month and a solar year. In the case of lunar month, it is not easy to decide when exactly new moon or full moon occurs. Similarly in the case of the solar year it is not easy to decide when exactly the earth completes one revolution around the sun. In the distant past it was decided by the duration between two consecutive onsets of the same season (say rainy season). In fact Hindi term for the year comes from वर्षा which means rain.

Besides these three units of time, people were also interested in knowing the location of moon relative to the neighboring stars from month to month. For this the path of the moon amongst the stars was divided into 27 more or less equal parts and each part was called a Naxatra which could be recognized visually by a specific group of stars located in that region. In fact each Naxatra is named after the brightest star in that group. Similarly the path of the sun relative to the neighboring stars was divided into 12 roughly equal parts called Rashis which were again named after the brightest star amongst the group of stars in that region.

It is important to note that a lunar month does not have exact numbers of days. According to present calculations it is around 29.530688 solar days. Similarly the number of days in a solar year is also not exact. It is around 365.242 days. In ancient India people do not seem to have been very adept in the use of fractions. To circumvent the use of fractions, scholars of the yore made use of the concept of ' Yuga'. A Yuga was the duration of time which had integer number of solar years, integer number of lunar months as well as integer number of days in it. (It is just like a vendor saying that the cost of two bananas is rupees five instead of saying that each banana costs rupees two and half. In mathematical terms it is the LCM of numbers involved).

It is thus clear that larger the length of a Yuga, more accurate will be the lengths of years, months and days in it when stated as whole numbers.

4.1 Five Year Yuga

A Yuga in Vedang Jyotish has 5 years, 1830 days and 62 lunar months. This results in (1830/5) i.e. 366 days in an year and the number of solar days in a lunar month to be 1830/62 i.e. 29.516 days. (Had the length of a Yuga been taken to be 1831 days, then the number of days in a lunar month would have been a bit more accurate. However the number of days in a solar year would have been 366.2. This would have been much farther from the correct value).

It is apparent that the length of Yuga chosen was too small. (It is just one year more than the present day leap year period of four which too has some error which is rectified when a century is considered a leap year only if it is divisible by 400 and not four thus reducing the number of leap years in a four hundred year period by 3). Of course the length of 29.516 solar days in a lunar month is a bit better estimate than 29 and a half solar days. However still it has some error. For example after a 20 year period, one would notice that when according to calculations it should be new moon in reality it would be a crescent (a difference of around three and a half days!). Such a result would have indicated that there was some basic mistake in the assumed length of Yuga. Later period books on Indian astronomy in fact assume a very large length of a Yuga. For example in Aryabhattiya (which was written in fifth century A.D.), a Yuga is taken to be of 43,20,000 solar years duration!

5. Fractions

It may not be construed that there is altogether no reference to fractions in Vedang Jtoyish. Wherever felt necessary a fraction was used by giving it a specific name. For example one hundred and twenty fourth part of a Naxatra has been named Bhansh. Expressed in terms of Bhansh, fraction 99/124 has been called 99 Bhansh and so on. Similarly a day was divided into 603 equal parts and each was called a 'Kala'. Again 'Kala' was further subdivided into 24 equal parts each being called a 'Kasth' which was further subdivided into five equal parts each being called 'Akshar'. Thus a day has 603 kalas, 603x24 kasth and 603x124x5 akshars. It is similar to the present day practice of dividing a day into 24 hours, each hour into 60 minutes and each minute into 60 seconds. Thus whereas a day has 24x60x60 seconds it has 603x 24x5 akshars. In a way an akshar is around one tenth of a second (a much smaller unit of time than the currently used second). Fortunately astronomers and scholars of Vedic era did not feel the necessity of using too many fractions. Otherwise there would have been a large vocabulary of the names of fractions. Specific names were given to only those fractions for using which a necessity was felt. The names were so framed that these could be conveniently incorporated into the desired shalokas for easy remembrance.

6. What is there in Vedang- Jyotish

As mentioned earlier, all the forty four shalokas of Vedang- Jyotish are not related to astronomy. The first four and the last one are not related to astronomy. Out of the remaining thirty nine, in twenty one shalokas there are definitions and discussions on the fundamentals. Terms such as 'Adak', 'Drina', 'Kundav', 'Nadika','Kashish', 'Mahurat' and 'Ritusesh' have been defined. It is also mentioned as to how many years, months and days are there in a 'Yuga'. Other similar facts of astronomical significance have been also mentioned. These include the exact locations of the sun and the moon in the sky at the beginning of a 'Yuga', and the times of the beginning of the north ward drift (उतरायण) and south ward drift (दक्षिणायण) of the sun. In one shaloka all the twenty seven Naxatras have been symbolically stated in a specific order. One shalokaa is about astrology in which inauspicious Naxatras have been named. Length of the longest day is also mentioned in one shaloka. This has great significance as it can be used to determine the latitude of the place of residence of the writer.

Of the remaining, sixteen shalokas contain computation rules. In one such shaloka a rule is given to decide as to when and which tithi is to be skipped. (Sometimes a tithi is skipped for example if today is 3rd tithi then tomorrow it should be 4th tithi. However if tomorrow it is 5th tithi, then 4th tithi has been skipped). This is called (क्षयतिथि). (The reason for skipping a tithi occasionally is that a lunar month is around 29 and a half days where as there are 30 tithis in a month. So in a two months lunar period there are 59 days but 60 tithis. As a result in general in a two month period a tithi has to be skipped to ensure relationship of tithis with days of the lunar month.)

In eighth shaloka, the locations of the moon amongst neighboring stars from new moon day to full moon day are given. In three shalokas it is explained as to how to locate the current position of the sun amongst the naxatras. Three shalokas explain the method for the computation of the time of occurrence of an equinox (when days and nights are of equal duration everywhere on earth). In another shaloka a method is given for computing the difference (भागांश) of the current position coordinates of the sun and moon. On account of its practical importance in astronomical calculations, this term has also been given several alternative names. In fact later day astrologers started using this to decide the auspicious and inauspicious parts of the day.

6.1 Tithis and Naxatras

Methodology for framing Panchangs which is being followed currently by the pundits is essentially the same as was in the Vedang period. Months indicate the movement of the moon relative to neighboring stars. One month being the time from one full (new) moon to the next full (new) moon. Each month is divided into 30 equal parts called 'tithis'. In order to ensure that each tithi gets associated with a specific phase of the moon, as explained earlier, in general one tithi is skipped every two months (occasionally a tithi is also repeated to account for over correction resulting from skipping of tithis). Again an year has 12 lunar months. Twelve lunar months of 29 ½ days each mean around 354 days in a year where as there are 365 and a quarter days in a year. This means roughly eleven days less in an year of twelve lunar months. If this difference had been left unadjusted, the seasons would not have kept pace with the months with which these are normally associated. In order to ensure that in the long run same seasons occur in the same months, an extra month (called adhikamas or malmas) was added every three years or so.

6.2 A remarkable Sutra

There is a remarkable sutra in Vedang Jyotish in which the names of all the twenty seven naxatras appear in their respective order. By counting its location in the sutra from the beginning and the end, it can be determined as to how far away from the moon this naxatra is at the time of new and full moon days! To select 27 words which represent the 27 naxatras, and then to so arrange them that they give the location of that naxatra relative to the moon on full moon day and new moon day, speaks volumes of the ingenuity of the scholars who composed it.

7. Period of Vedang-Jyotish

Position of the sun amongst the stars on a solistice is mentioned in Vedang-Jyotish. The position of sun amidst neighboring stars does not remain fixed. It slowly shifts from year to year. In fact sun recedes slowly along the ecliptic making one complete revolution in 26000 years. This fact can be used to estimate the time period of Vedng-Jyotish. Calculations give this period to be around 1200B.C. However many of the western astronomers are not willing to accept thus far antiquity of Vedang Jyotish. According to them it is not easy to compute the precise positions of the sun visa-vis the surrounding stars even now. So the positions recorded there might be having some error. It is also possible that the writer might have stated the positions from some earlier records. Both these doubts cannot be completely brushed aside.

However in spite of all such misgivings, the above stated facts as well as certain other relevant information suggest that it will not be out of place to accept that the period of Vedang-Jyotish was indeed around 1200 B.C.

8. Writer of Vedang-Jyotish

In shaloka two of Vedang Jyotish of Rigveda and shaloka 43 of Vedang Jyotish of Yajurveda, it is mentioned that the writer got this knowledge from rishi Lagdha. However who the actual writer of Vedang Jyotish was, is no where mentioned. Based on the first shaloka of Vedang Jyotish some regard Suchi to be its writer since it is mentioned in this shaloka that 'I, Suchi will tell------------`. However some others are of the view that Suchi is not the name of author. It refers to its literal meaning which is 'purification' and the shaloka states that 'I after purification,---------.

It is also not easy to tell who actually Lagadha was. This name does not appear elsewhere in Sanskrit literature. The word also does not seem to have Sanskrit roots. Therefore some scholars are of the view that Lagadha was perhaps a foreigner and the astronomy related information mentioned in Vedang Jyotish might be having some foreign origin.

8.1 Location of the Writer of Vedang Jyotish

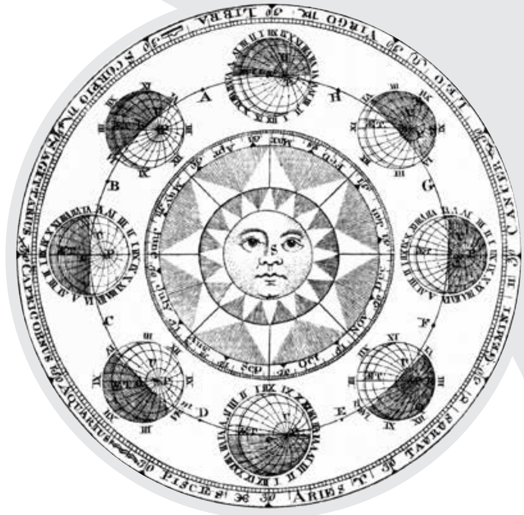
The length of the longest day in an year is mentioned in Vedang-Jyotish. This can be used to calculate the latitude of the place of the writer. Calculations show that the latitude of the place of the writer was around 35 degree North. In the Indian subcontinent this latitude is in northern Kashmir and Afghanistan. It is therefore likely that the writer of this work might have been living in one of these two places. Even in those days, the length of a day could be measured with reasonable accuracy with the help of time clock made of a pot with a fine calibrated hole at its bottom placed in a tub containing water. The passage of time was measured with the gradual rise in the height of the water in the pot. Therefore there does not seem any reason for suspecting the length of the longest day as mentioned in Vedang Jyotish.

9. Some Critical Obervations

There are certain facts which should have been mentioned in Vedang Jyotish but are not there. This is probably in view of its very compact format. Some of these are:

It has been mentioned no where that the angular velocities of the sun and the moon are not uniform and that the velocities mentioned are average velocities. All computations mentioned are based on uniform angular velocities for the both these heavenly bodies. That is perhaps why all the tithis in Vedang Jyotish are of equal duration which in reality is not so. In astronomical works of later period (such as Surya-Siddhanta) there is mention of non uniform angular velocities of the sun and the moon, as a result of which the durations of all tithis are not equal. It is possible that the writer of Vedang Jyotish was not aware of this fact. It is also possible that uniform angular velocities had been assumed for computational convenience. However had it been so then this fact would have been mentioned.The writer of the Vedang Jyotish was perhaps also not aware of the obliquity of the ecliptic which is the cause of non uniform angular velocities. It is likely that in those early times such minute observations were not possible.

Unfortunately between 1200 B.C. and 500 A.D., there is a very long gap in which no work on Hindu astronomy is now available. Around 500 A.D. a number of books on astronomy appeared in India. These will be discussed in subsequent chapters.



05

ASTRONOMICAL REFERENCES IN RELIGIOUS SCRIPTURES

1. Introduction

After Vedang Jyotish no specific records of the evolution of Astronomy in India are available for the next one thousand years or so. From Kautaliya`s Arthshastra (which was written around 300 B.C.) it appears that till that time not much progress had taken place in the field of astronomy from its status as mentioned in Vedang Jyotish. A book on astronomy written around one hundred years after Arthashastra is available. This book describes the structure of universe as mentioned in religious scriptures. Astronomical facts mentioned in the book are similar to those mentioned in Vedang Jyotish. Even after that work, we do not have record of any work of significance on astronomy for another hundred years when in the year 499 A.D. a book on astronomy titled 'Aryabhatiya' written by Aryabhata appeared and this work is available even now.

It is possible that after Vedang Jyotish there might have appeared on the scene some important astronomers prior to Aryabhata also. However their works are not now available. There is a reference to Jyotishi (Astronomer) Garg at several places in the literature of that period. It is mentioned in Mahabharta that Garg was astronomer/ astrologer of king

Prithu. It is likely that his reputation was more on the basis of his astrological predictions than his astronomical contributions. A later period astronomer Varahamihar refers to Garg in his astronomical work 'Virihit-Sanhita' which is more related to astrology than astronomy. For example in this work Varahamihar writes, 'I say on the authority of Rishi Garg that the Saptrishi star cluster is in Megha rashi'. Again he writes, 'In the abode of devtas on the mount Meru, Narad gave information about Rohini Yoga to Brahaspati. The same rules were taught by Garg, Prashar, Kashyap and Maya rishis to their pupils. I am writing this book after studying these rules.` He also writes at another place that what he was writing about Ketu, was what he had learnt from the works of Garg, Prashar, Asit Deval and others.`

All this shows that there were some astronomers/astrologers as well as their works during this period. However not much is known about them or their works. The only reliable source of information regarding the status of astronomy of that period are the astronomical references which occasionally appear in the religious scriptures of Hindus, Jains and Buddhists of that period.

2. Manusamriti

According to Hindu religion and as mentioned in the Rig Veda, Manu is the legendary father of mankind. He codified laws for Hindu society which are mentioned in Manusamriti. Chapter 1 of Manusamriti contains certain verses which specify units which were in use for the measure of time. When translated into English these verses state (text in parentheses as added by Buhler in his translation (1886)).

(64) Eighteen nimeshas (twinkling of eyes) are one kashtha, thirty kashthas one kala, thirty kalas one mhurta and as many mhuratas one day and night.

(65) Sun divides days and nights, both human and divine, the night (being intended) for repose of created beings and the day for work.

(66) A month is a day and night of the manas and division is according to fortnights. Dark (fortnight) is their day for active exertion, and the bright (fortnight) their night for sleep.

(67) An year is a day and a night of the gods. Their division is (as follows): the half year during which the sun progresses to north is their day, and the half year during which sun moves southward is their night.

(68) But hear now a brief description of the duration of night and day of Brahman and the ages of the world (yugas) according to their order.

(69) They declare that the Krita Yuga (consists of) four thousand years (of gods) the twilight preceding it consists of as many hundred years and the twilight following it also of the same numbers of years.

(70) In the other three Yugas, with their twilights preceding and following, the hundreds and thousands are diminished by one each.

(71) These twelve thousand (years) which thus have just been mentioned as the total of four (human) Yugas are called one Yuga of the gods.

(72) But know that the sum of one thousand Yugas of the gods (makes) one day of Brahman and his night is also of the same duration.

(73) Those (only who) know that the day of Brahman ends after (completion of) one thousand Yugas (of the gods) and that his night also lasts as long, are really acquainted with (lengths of) days and nights.

(79) The before mentioned age of gods (or twelve thousand of their years being multiplied by seventy one) constitutes what is named a period of Manu (Manvantra).

(80}. The Manvantras (the creations and destructions of the world (or cosmos)) are numberless; supporting as it were that Brahman repeats this again and again.

Common interpretation of this at present is that Manu described the lengths of ages in years of gods which are 360 times the human years.

3. Astronomy Related References in Ramayna

Two important scriptures of Hindu religion which belong to the post Vedic period are Ramayna and Mahabharta. Of these two, Ramayna is considered to be a narrative of events that happened much earlier than events narrated in Mahabharta. There are very few references in Ramayna which throw light on the status of astronomy of that period. Some of the references of astronomical significance in Ramayna are that Rama was exiled for a period of thirteen years and at the expiry of twelve years, Ravana abducted Sita. This indicates that people of that Era were well aware of the duration of a year. Again it is mentioned that during their search of Sita after her abduction by Ravana, Rama and Laxaman were held up because of the onset of rainy season. On observing naxatra associated with the end of rainy season appearing in the eastern horizon, Rama remarks that as naxatra Augustus has appeared in the eastern horizon it means the end of rainy season, there by indicating that people then were aware of the association of the seasons with the appearance of different naxatras in the sky.

4. Astronomy Related References in Mahabharta

Mahabharta contains several references to Astronomy as well as cosmology. Pandavas were exiled for 13 years with an additional condition that they would have to spend 13th year incognito and that in case they were recognized in the 13th year, the period of exile would get extended by another 13 years. After spending 12 years of exile in jungles, Pandavas shifted to the state of Taxila in the North West of India (now in Pakistan) and started serving incognito in the court of the King of Taxila. No one was aware that they were Pandavas. Time passed. However on account of some conflict with a neighboring state, the king of Taxila had to wage a war with that neighboring state in the East. Since Arjun and Bheem were both well built and robust and expert in warfare, the king of Taxila asked them to fight in this war along with his forces. Being in the service of the king, they could not refuse and obeyed. Perchance, Kaurvas were fighting on the side of the opponent. In the battle field, Kauravas recognized Arjun and Bheem and said that since full 13 years of exile had still not been completed, and Pandavas had been sighted, their period of exile was to get extended by another 13 years. Pandavas on the contrary claimed that the 13 years period of exile had expired before the beginning of the war and so there was no question of their exile period being extended. However Kauravas contested it. When this dispute was referred to Bhishma by Daryodhna, Bhishma replied as under (Virat Parv Aa 52).

As time passes, each five year period has two extra months besides 12 months of an year. So in a period of 13 years there cannot be more than five Adhmas. As a result Pandavas are right and the thirteenth exile year was over 12 days before the start of the war.` However Daryodhan contested it. According to him 13th year was still not over as an extra month was to be added that year also. Computations of Bhima were on the basis of Vedang Jyotish after making due adjustments for the recession of equinoxes. During Vedang Jyotish period, Uttrayan (the instance when the sun starts moving north in the horizon) commenced when the sun entered Ghanishta rashi. However because of recession of equinox this point of entry of sun in Uttrayan shifts about one naxatra (1/27 of a complete circle) in 1000 years. As a result during Mahabharta period Uttrayan did not commence when the sun was in Ghanishta naxatra. This fact is also mentioned elsewhere in Mahabharta (Adi Parv Aa 71).

4.1 Count of the Passage of Time

In Mahabharta period, the units being used for recording the passage of time were essentially the same as mentioned in Manusamriti. Life of the universe was being divided in to four parts. These were named : Krit (or Sat) Yuga, Trita Yuga, Dvapar Yuga and Kalyuga. Each Yuga starts with 'Sandhya' and ends with 'Sandhyansh'. The count of years in each Yuga was as under:

Yuga	Years	Yuga	Years
Krit (Sat)	Sandhya 400 Main 4000 Sandhyansh 400	Dwapar	Sandhya 200 Main 2000 Sandhyansh 200
Treta	Sandhya 300 Main 3000 Sandhyansh 300	Kalyuga	Sandhya 100 Main 1000 Sandhyansh 100

Four Yugas taken together constitute one Deva Yuga which is 12,000 years. According to some experts, the years mentioned above are not human years but years of Devtas, making in all 4,320,000 human years. This is half cycle. A day of Brahma is 1000 times this half cycle and the same is the duration of Brahma's night. So a cycle of day and night of Brahma is 8,640,000,000 human years!

According to modern theories of science, the earth was born several thousand million years ago. Above figures also show that according to the knowledge of ancient rishis of India, the life of earth is also of the same order. This is in great contrast with the beliefs of the religions of the west according to which the life of the earth is not considered to be more than 4000 years!

There is mention of five years Yuga also in Mahabharta. A stanza in Adi Parva (Adi Parv A.124) mentions that five Pandvas were born with a gap of one year each like 5 years of a Yuga.

Some consider Sanskrit word Varsh for an year as an indicator of the onset of rainy season. According to them since in the distant past new year was being taken to start with the onset of rainy season, it started being called Varsh

4.2 Cosmology

Mahabharta also contains some references to cosmology. For example in Mahabharta (3.43.30) it is mentioned that stars are luminous and very big but appear small and twinkle like earthen lamps (diyas) on account of their great distances.

Another famous saying in this regard is 'Sarva danishta, Surya, Surya, Surya' meaning suns, suns in all directions, implying thereby that the stars that surround us in all directions are themselves suns but much farther away than our sun.

Vishwamittra on getting enraged created a new world and new naxtras that started with Sharavana. Mentioning Naxatras starting with Shravana indicates that by then count of Naxatras starting with Shravana had commenced. This implies that during that period, either ascending or descending node of the ecliptic from where the sun starts its northern or southern movement from East point on the horizon would have been occurring close to Shravana Naxatra. Out of these two, the greater probability is when sun starts shifting north. Computations show that this was possible around 450 B.C. (indicating the likely period of Mahabharta).

There is no mention of the days of the week (Sunday, Monday etc) in Mahabharta, implying there by that names of week are of a later origin. Terms Yog, Karan or Rashi also do not appear. These also seem to be of a later origin.

4.3 Uttrayan and Dakshnayan

In Mahabharta the dates were generally counted with respect to the moon. However at places we also find mention of dates with respect to the sun. For instance (Vanpurva, Aa, 200) it is mentioned that alms given on a new moon day or a full moon day are double blessed, alms given at the start of new season are ten times blessed and alms given at Uttrayan and Dakshnayan and lunar and solar eclipses are hundred times blessed.

Uttrayan and Dakshnayan are respectively Makar Sankranti and Karak Sankranti. It is thus clear that during Mahabharta era, the path of the sun in the sky was being divided into 12 parts corresponding to 12 months of the year. However names of rashis do not appear in Mahabharta. It thus appears that present day names of rashis are of some later origin.

4.4 Eclipses

As regards eclipses of the sun and the moon, the term eclipse appears at several places in Mahabharta. People then were aware that an eclipse can occur only on a new moon or a full moon day. An eclipse was considered inauspicious. It is mentioned that when Pandavas were exiled, an eclipse of the sun had taken place even though it was a new moon day (Sab parva Aa 79). Happening of two eclipses, one of the sun and the other of the moon with in thirteen days of each other at the start of Mahabharta war was also considered very inauspicious (Bhism Parva Aa 3). It is stated that on full moon day in the month of Kartika, moon became dark and disappeared. Then it took color of burning fire. Usually new moon day occurs 14th or 15th day (and sometimes even 16th day) after full moon day. But at that time it had occurred after 13th day of the full moon, and the author was not aware of such a happening earlier (when a solar and a lunar eclipse happened in the same month and that too within thirteen days of each other).

This shows that people at that time were aware of the fact that two consecutive eclipses, one solar and one lunar, could happen within 13 days of each other (but of course very rarely). It is difficult to say with certainty whether such an event really happened on that occasion or the author of Mahabharta wanted to highlight it as the occurrence of a bad omen at the beginning of the war. According to calculations of Shankar Balkrishna, the duration between new moon and full moon in the month of Phalgun of Shaksamwat 1793 was 13 days. Same was the case in the month Jeshtha of Shaksamwat 1800. However duration of half month being just 13 days is rather rare. According to modern calculations , variation in the duration of a half month is due to the variable velocities of the sun and the moon in their orbits. How two consecutive eclipses can sometimes happen within thirteen days of each other can be briefly explained as under.

In Indian system of astronomy, a new day begins with the rise of the sun. Suppose there is an eclipse up to even a few minutes past the sunrise on Jan 1. Then it will mean that there was an eclipse of the sun on Jan 1 (even though most of it happened before sunrise). Now if the next eclipse happens even at late night on Jan 14, it would imply that two eclipses have occurred within 13 days of each other. Even though in reality almost 14 days have passed between the two events.

However it seems that the author used it to highlight the gravity of the event as the same phenomena is mentioned to have occurred even when Pandavas were sent in exile as well as at the time of the death of Duryodhan (Gada Parv Aa.17).

It is mentioned in Mahabharta that when a solar eclipse occurs, the sun is swallowed by the demon Rahu. This shows that at that time people were perhaps not aware of the real cause of the eclipses. However they were aware that a solar eclipse happens only on a new moon day when the sun is near Rahu (one of the two points of intersection of the paths of the sun and the moon in the sky). Number of Rashis mentioned in Mahabharta is five at some places and seven at other places (when Rahu and Ketu are also considered Rashis). May be they were aware of the true cause of eclipse as well. However there is no clear mention of it.

4.5 Grehas

There is mention of Grehas (planets) also in Mahabharta. In Bhisham parva Aa 100, it is stated that just as five Grehas surround the sun, in the same way on being enraged, the five Pandavas surrounded Alambush Raksha. People were also aware of the forward and backward motion of the planets (Karan Parva 4). Locations of planets amongst stars are mentioned at several places. For instance in Bhisham Parva A3, it is mentioned that Rishi Ved Vyas informed Dharitarshtra that the battle of Mahabharta would start in the month of Kartika when Ketu, after having crossed star Chitra, will be near the star Swati. At that time a ferocious looking tail star (comet) will cross star Pushpa. Planet Mars will be near the star Megha. Planet Brahaspati (Jupiter) will be near Shravna and in retrograde (backward) motion. Moreover Purva will be near Bhadrapada Nakshatra and the planet Shukr (Venus) will also be visible. Sun and moon will be both in Rohni rashi and Parush between Chitra and Swati. Mars will be bloody red and will eclipse an auspicious star. Bright Jupiter and Saturn will be near Vaishakha Nakshatra for about an year. According to rishi Ved Vyas, the author of Mahabharta, all these are very inauspicious omens. This shows that during Mahabharta era, people were also aware of the planets and their forward and retrograde motions.

Dr.S.Balkrishnan (of Indian Institute of Science Bangloru(Banglore,India) ,tried to use the occurrence of two consecutive solar eclipses within a span of thirteen days and both visible from Kurukshetra to estimate the likely period of Mahabharta. He searched for all such pairs of occurrence from3300 B.C. to 700 B.C. and found eighteen such pairs. Of these the earliest to occur was in 3129 B.C. and the latest in 1397 B.C. Based on these findings, and some other collaborative evidence, he is of the view that the dates mentioned by Aryabhatta and Varahamihar for the Mahabharta period seem credible.

5. Astronomy related references in Religious Literature of Jains

Ardha-Magadhi Prakrit texts have been composed from the oral traditions of the original Jain texts known as Punvas. This recasting was undertaken by Svetambra sect. These texts are 45 to 50 in number. These texts are divided into Angas and Upangas. Astronomy related matters appear in two Angas namely: Sthananga and Bhagavati Sutra. Amongst upangas astronomy related matters appear in Suryaprajnapati, Chandraprajnapati and the seventh section of Jambudvipa prajnapati.

Jain post canonical literature such as Tattvarthadhigama Sutra by Umasvati (185-219 A.D) is on astronomy and cosmology. Twenty seventh chapter of seven thousand verses, Trilokaprajapati by Yati Vrshbha (473-609 A.D), is also on astronomy. Jyotisakarandaka by Padaliptacharya contains totality of Jain religion`s view on astronomy. Karana Yoga or Ganita Yoga of Digamber sect is a comprehensive text of the views of Jain religion on astronomy.

Although on most of the topics there is not anything substantially different from those mentioned in Hindu epics, the views of Jain religion on cosmology are substantially different from those of Hindu cosmology. According to Jain cosmology, mount Meru is the central axis of the earth which is regarded motionless. This along with stellar constellations, planets, continents, rivers, seas and mountains constitute Jambudvipa (literally, 'rose-apple land`). Awareness of connectedness of subjective reality of all creation is expressed through Jambuvriksha (world tree). Cosmic diagrams of Jain literature depict Mount Meru at the centre with outer most limit as the twelve months, planetary cycles and movements of the sun and the moon. Polar star is depicted as being directly above the Mount Meru.

6. Astronomy in Buddhist Scriptures

Buddhism does not hold astrology and astronomy in high esteem. Therefore not much material related to astronomy is available in Buddhist literature. It is mentioned in Buddhist scriptures that some Brahmins and Pandits earn their livelihood in a very disgraceful manner. They make predictions regarding solar eclipse, lunar eclipse, eclipses of planets, forward and retrograde movements of the sun, the moon and the planets which are supposed to be the causes for the occurrence of earthquakes and can also lead to other horrific events such as the sun, the moon and the stars rising in the west and setting in the east. According to Buddhism such predictions are fragments of imagination and are made to scare common people and make them give liberal alms.

06

ASTRONOMIES OF THE WEST

1. Introduction

In the distant past humans, not only in India but elsewhere in the world also, must have been fascinated and excited about heavenly objects such as the sun, the moon and the stars, their rising and setting, as well as the waxing and waning of the moon. They must have also thought of putting these observed natural phenomena to use particularly for recording the passage of time.It is therefore but natural to expect that the essential fundamentals of astronomy must have sprouted on their own spontaneously in different parts of the world where human civilization had taken roots and people had started living in villages and helmets and started cultivating land and rearing domesticated animals. It is only later on when the means of travel and communication grew and developed that the knowledge of astronomy like other subjects would have started traveling from one civilization to the other.

It is a bit difficult to believe that only one single civilization had monopoly over the knowledge of the basic essentials of astronomy and other civilization learnt from it. Besides India, some other centers of civilization in the distant past were Babylon, Greece, Arabia and China. There was also a Maya civilization in American continent. However it developed aloof on its own for long and came in contact with the rest of the world only a few centuries back.

2. Astronomy in Babylon

Ancient residents of Babylon had developed considerable knowledge of astronomy. They lived in the land between the rivers Tigris and Euphrates in Western Asia. They had devised

'Yuga' named `Seryas` to predict eclipses. Yuga was about 223 lunar months (around 18 years and 11 days) and in each Yuga eclipses repeat in the same order and also at the same time. It is not easy to pin point as to when this concept of Yuga evolved. Writings of a king of Babylon of the distant past show that by 3800 B.C., certain star clusters had been named. No doubt these names later changed slightly over the ages from time to time. Some baked earthen pallets have been found in Mesopotamia (present name of Babylon) on which pieces of information of several types are inscribed. Linguistic experts have been able to decipher these. These pallets show the extent to which knowledge of astronomy had progressed in Mesopotamia by 2nd century B.C. Babylonians knew that the planets mars, mercury, saturn and jupiter return back to their original positions relative to the neighboring stars after a certain number of years which varies from planet to planet. Each year a panchang inscribed on pallets was published. On these pallets, dates of new moon, full moon, dates of occurrence and description of eclipses, times of rising and setting of important stars and locations of various planets were also mentioned. Their solar year was four and a half minutes longer than the actual sidereal year.

3. Astronomy in Greece

Greeks seem to have got their knowledge of the basic fundamentals of astronomy from Babylon. They got from Babylon the knowledge of the positions of stars in different clusters as well as the knowledge about planets. The knowledge of star clusters which Greeks got from Babylon has been expressed in verse form by Greek poet Eratas. He has referred to the locations of star clusters as these existed around 2800 B.C. This is so because the presently known star clusters whose names do not appear in his narration must be those which were not visible in sky of Greece at that time. Greece being in northern hemisphere, such clusters must have been around the South Pole. This gives us an idea about the location of South Pole amongst the stars at that time. The position of North and South poles is not permanently fixed relative the neighboring stars. Stars around the poles in fact make small circles about the poles in around 26000 years. As a result of this, knowing the location of star clusters as given in old star charts and comparing these with their corresponding present day positions, one can estimate as to when those star charts might have been prepared. Using this technique, it appears that Eretas wrote his narrative in 270 B.C. However the description of star clusters mentioned in his narrative points to the charts having been prepared around 2800 B.C. from a location in a country situated in 40° north latitude. Priest F.X.Kugler discovered that the length of lunar month in Babylon was exactly same as mentioned by eminent Greek astronomer Hippochrus. This shows that Hippochrus got his knowledge of the lunar month from Babylon.

Considerable knowledge of astronomy had traveled from Babylon to Greece by 7th century B.C. Around 640 B.C., a Babylonian started his school of astronomy in Kas island of Greece. Thales was most probably one of his pupils. Pythagoras traveled through Babylon, Egypt (and perhaps even India) around 530 B.C. Based on the information that he collected from these countries and combined with his own discoveries, he had acquired a reasonably good knowledge of mathematics and astronomy(it is the same famous Pythagoras after whose name there is a well known theorem in plane geometry according to which in a right angled triangle, the sum of the squares of the lengths of the sides adjacent to the right angle is equal to the square of the length of the third side opposite the right angle (called hypotenuse)). Pythagoras believed that the earth is standing on its own in space and is not on any support. Later writings of his pupils also confirm that he also believed that the earth is rotating about its axis. Aristacuras (around 28-234 B.C.) believed that the sun is stationary and earth and other planets revolve around it. Vdocasts (408-355 B.C.) had given a correct explanation as to why planets appear to move to and for in the sky about their mean positions instead of always moving in the same direction. Later on some other astronomers introduced minor modifications in this hypothesis. This finds mention in Surya Siddhanta also and was more or less accepted as such for around 1800 years after Appoloneous.

Aristotle and Timore (around 320-260 B.C.) prepared star charts indicating positions of stars in the sky. Aristocurs also mentioned techniques for measuring distances of the sun and the moon. These are correct in principle but do not yield good results. Aristasthinij measured angle between the ecliptic and celestial equator. His measurement is in error by just 5 kala. He also computed the circumference of the earth by measuring the angles of elevation of a pole from two different places on the earth.

Hippochrus and Tolmy were by far the most eminent Greek astronomers of the past. Dates of birth and death of Hippochrus are not exactly known. However it is well established that he lived and worked around 146-127 B.C. He is counted among the most eminent astronomers and mathematicians of the past. He was born in Nishia. After working at his birthplace for sometime he shifted to Alexendria and conducted there his astronomy related research during 161-146 B.C. His original manuscripts are now practically lost. However we get information about his work from the writings of Tolomy of Egypt and Strabo (first century B.C). Tolomy has referred to Hipochrus at several places in his book 'Al Majesty'. This book was held in high esteem like religious scriptures such as Vedas till the times of Copernicus (1473-1546 A.D) and Kepler (1571-1630 A.D.) and that is perhaps why it remained preserved.

In his writings Tolomy speaks highly of Hippochrus and has been at pains to mention as to what he had learnt from Hippochrus. At places it is even difficult to distinguish between his own original work and that of Hippochrus. It seems that Hippochrus wrote several notes about his findings but did not put those in the form of a book. Tolomy came around 300 years after Hippochrus. Basic problems of astronomy had already been resolved. Tolomy essentially formalized them and filled the missing gaps and prepared updated astronomical tables.

4. Contributions of Hippochrus

Hippochrus was able to determine the length of sidereal and solar years, the length of a lunar month, periods of revolution of the then known five planets, shape of the ecliptic, inclination of the ecliptic to the equator, inclination of lunar path to the ecliptic, perihelion of the ecliptic (when the sun is farthest from the earth in the annual motion of the earth around the sun), and the distance of the moon from the earth. Surprisingly all these measurements made long back in the hoary past were reasonably accurate. No doubt much of this information he had obtained from Khalids who later on occupied Babylon. However it is also a fact that he had made his own observations and calculations as a result of which he had improved upon the earlier results. Hippochrus used to analyse the behavior of stars in the sky by plotting them on a sphere. It is done even now .Such a sphere is called`Celestial sphere`. With the help of such a sphere he could properly represent relative positions of different star clusters that appear in the sky.

It is quite possible that Hippochrus was also using some crude form of telescope for observations. It is indeed surprising that he could make reasonably accurate observations with even crude observational instruments which were available at that time. He had also come up with a reasonably accurate theory which could explain observed motions of the sun and the moon. However, he was not successful in explaining the to and fro motions of planets about their mean positions. It was later done by Tolomy. Hippochrus did not accept the hypothesis of Aristocrs that sun is stationary and it is the earth that revolves around it.

One very important and note worthy finding of Hippochrus was the fact regarding the slow backward motion of the point of intersection of ecliptic and equator along the ecliptic. As a consequence the time which sun takes to make one complete revolution of the ecliptic is slightly different from the time it takes to make one complete revolution relative to other fixed stars in the sky. The first is called solar year and the second sidereal year. The difference is just around 27 minutes and 23 seconds. Hippochrus was aware of this even that for back in history. Surprisingly astronomers in India only became aware of it 700 years later. (Most of Indian Pnchangs till date make no distinction between the two.)

In fact Gamma, the first point of Aries star cluster, where the ecliptic and the celestial equator cross each other (also called spring equinox), recedes slowly backwards along the ecliptic making one complete revolution of the ecliptic in around 2600 years. (It takes almost 36 years to recede along the ecliptic as much as the diameter of the sun itself). Hippochorus became aware of it while comparing his observations with those of Timocurus. However he became fully convinced of it only when he compared his own and Timocrus`s observations with those of Khalids of Babylon. His estimate of the rate of backward motion was around 36 ″ per year where as in reality it is 51″ per year.

Hippochrus had also compiled a catalogue of stars. This catalogue had 850 stars. Their positions had been mentioned in terms of their longitudes and latitudes. Perhaps the idea behind the preparation of this catalogue was to check if an observed star is the one already included in the catalogue or a new star. In fact during the times of Hippochrus a new bright star became visible in 134 B.C. and it has also been referred to in records of Chinese astronomers. Later on Tolomy again published his catalogue after making minor corrections.

5. Tolomy

Tolomy was a resident of Egypt. His full name is Kaladues Tolomus. Tolomy was a great astronomer and mathematician. Nothing definite is known about his dates of birth and death. However according to an ancient Greek writer, he was born in Tolomurs Harmai city in Greece and his active period of work was between 127 to 141 or 151 A.D. According to an Arab writer he died at the age of 78 years.

Certain results established by Hippochrus in plane and spherical trigonometry helped Tolomy establish some new results in observational astronomy. In fact his work on these topics was so perfect and complete that no further progress in that direction took place in the next almost 1400 years! The book in which his work on mathematics and astronomy was published is called 'Mathematica Synataxis' by the Greeks. Arabs called it 'Al Majesty' a sort of tribute to the author. This Arabic name of his work was later retained in translations into English and several other European languages.

The first part of this book is devoted to earth (its shape, its unsupported existence in space), motions of heavenly objects in circles, methods for measuring angular motions, tables of angular motions of important heavenly bodies, inclination of the ecliptic and the method for measuring it, relevant results from plane and spherical trigonometry, methods and tables for conversion from one coordinate system into another. In the second part of this book some basic and fundamental questions regarding astronomy have been answered (for example how to determine the length of the longest day at a given place on earth). In the third part of the book three different lengths of the year, shape of the ecliptic and computations regarding the positions of stars relative to it have been explained. These results are primarily based on the premise that the sun moves on the circumference of a circle whose centre moves on another circle. (According to Tolomy the propounded hypothesis should be as simple as possible and the available observations should not contradict it.)

In the fourth part of the book, the length of a lunar month, and the motion of moon are discussed. Part five is devoted to techniques for making astronomical instruments, measuring diameters of the sun and the moon, measuring the length of a shadow and the distance of the sun.

Part six of the book is primarily devoted to the eclipses of the sun and the moon. In part 7 a catalogue of stars in the northern hemisphere is given. Catalogue of stars in the southern hemisphere is given in part 8. Total number of stars included in both the catalogues is 1022. Position coordinates as well as the brightness of each star is mentioned. Milky Way has also been mentioned in part 8. Part 9 to 13 are devoted to information about planets.

Several commentaries have appeared on this monumental work . Papus wrote a commentary on it in Greek. Theon wrote a commentary on it around 400 A.D. It was published in 1568 A.D. A translation of Syntax in Arabic was published in 827 A.D. Later several more translations in Arabic appeared. One of these was later translated into Latin in 1157 A.D. A direct translation from Greeek to Arabic appeared in 1451 A.D. Hieberg published authentic editions of Tolomy's works in 1899-1907 A.D. Some translations had appeared earlier also. A German translation appeared in 1912-13 A.D.

Almajesty was the pinnacle of Greek astronomy. In fact after Tolomy no eminent astronomer appeared on the horizon of Greek astronomy for the next one and a half thousand years.

6. Astronomy in the Arab world

Albouroni is considered to be the pioneer in formulating essential fundamentals of Arabic Astronomy. Albouroni himself admits that he got knowledge of astronomy both from India and Greece. To begin with he could get hold of two to three Indian works on astronomy. This was during the reign of second Abaasid Khalifa Almansoor (773 A.D). This finds mention in the astronomical catalogues of Bin-Al-Admi. These were published in 920 A.D. It is mentioned there that an astronomer of repute of Indian origin had come to the court of Khalifa and he had brought with him books on astronomy containing tables of planets, computations related to the predictions of the eclipses of the moon and the sun which he claimed that he had copied from the authentic works of well known Indian prince Ficher by name. The fact that Arabs were aware of Indian astronomy before they became aware of Greek Astronomy is documented in the Arabic translation of Syntax. This was later translated in to different European Languages. In the Latin translation of this work, the ascending node has been named 'Sir wala pat' and descending node 'Pooch wala pat' which are literal translation of the words Rahu and Ketu of Hindu astronomy. Other sources and references also confirm that there had been a deep impression of Hindu astronomy on Arab astronomy in the distant past. Major contributions of Arabs were primarily in synthesizing knowledge of astronomy which they got from the east and the west.

7. Interaction between Indian, Greek and Arab Astronomies

There are many similarities between the basic fundamentals of Indian and Greek astronomies. For example

(i) Orbit of the moon being divided into 27/28 parts (called Nakshatras). (Same is also true with slight variations in the case of Arab and Chinese Astronomies.)

(ii) Ecliptic, the orbit of the sun on the celestial sphere, being divided into 12 parts (called Rashis).

(iii) Days of the week being seven in number and those being named after the sun, the moon and the five major planets known to the ancients.

These facts lead one to believe that perhaps astronomy first originated either in India or in Greece and then travelled to the other parts of the western world through Arabs. It is of course apparent that in the distant past information could be communicated and transmitted in brief about the essential basic fundamentals only. It was not possible to transmit it in detail. Some Western scholars such as Whitney believe that essentials of astronomy first sprouted in Greece and then travelled east to India through contacts such as the invasion of India by Alexander. However other scholars such as Brijesh do not agree with this. They are not willing to accept that the basic essentials of astronomy came to India from Greece. No doubt after the invasion of India by Alexander, communication channels got established between India and Greece through Arabs and knowledge of mathematics and astronomy traveled to the west and east through Arabs. In fact Arabs acknowledge this fact when they term numerals as Hindse (meaning from India). The western world came to know of these numerals (0, 1, 2, 3,-----, 9) from the Arabs and so they now call these Arabic Numerals.

Another view can be that the basic fundamentals of astronomy had their common origin somewhere in the Arab world and from there they traveled west to Greece and east to India.

In fact with the passage of time there has been greater interaction between the Western, Arab and Indian astronomies and each has learnt something from the other. In most of the cases, Arabs have served as go in between.

07

ARYA BHATTA-I

1. Introduction

With the gradual decline of Buddhism in India, Hinduism again started flourishing during Gupta period. This gave fillip to the study of Jyotish (astronomy and astrology). By that time contact with Arab and Greek astronomers of the west had also started growing. This resulted in emergence of several Indian astronomers of eminence in the Vikrami sixth century. Whereas some of these astronomers wrote books on astronomy based purely on ancient Indian astronomy, some others added to it some information and discoveries obtained from the west.

Amongst the earliest astronomers of this era, Arya Bhatta gained maximum fame and repute. He was born in 476 A.D. and wrote a famous book on astronomy titled 'Aryabhatti'. In fact it appears that beside this book he had also written another book on astronomy. This becomes evident from the works of later date astronomers such as Varahamihar and Brahma Gupta. However his second book is not now available and has been lost in oblivion. Later on, in the year 950 A.D., there appeared on the horizon of Indian astronomy an astronomer of fame by the same name. He also wrote an important book on astronomy titled 'Maha Siddhanta'. In order to distinguish the two we shall be referring to the present Arya Bhatta as Arya Bhatta-I and the later one as Arya Bhatta- II.

2. Arya Bhatta-I

Arya Bhatta –I (sometimes also called Arya Bhatta the elder) was born in 476 A.D. in Ashmaka (or Kusumpura). In fact he is the earliest Indian astronomer whose work on astronomy and mathematics is now available in the form of a book titled `Aryabhatti`. He studied astronomy at the ancient observatory of Khagol (astronomy) at the University of Nalanda. He lived in Kusumpura near Patliputra (modern Patna) which was then the capital of Gupta dynasty. He composed at least two works on astronomy, namely: Aryabhatti and Aryabhatta Siddhantta (the second book is lost and not now available). Aryabhatta Siddhantta was popular in the north western part of India and Iran. It had profound influence on the development of Islamic astronomy. Its contents are to some extent preserved in the works of later period astronomers. Aryabhatti on the contrary became more popular in southern parts of India. Written in verse form it deals with topics related to astronomy as well as mathematics.

3. Aryabhatti

Arya Bhatta was a renowned astronomer of his times. Before writing Aryabhatti he had carefully studied important available works on astronomy. Starting with an introduction, the work is divided into three parts namely: Ganita (Mathematics), Kal-Kriya (Time calculations) and Gola (Sphere or Celestial sphere). Writing style of Aryabhatti is very compact. The shaloka in which he mentions his birth simply states that in the 3600th year of Kalayuga he was 23 years old. There are 121 shalokas in all. These have been divided into four parts. Of these four parts, the first one, namely introduction (Geetikapad) is the smallest. It has just eleven shalokas. However a very large amount of information has been compressed in these eleven shalokas. For achieving this, Arya Bhatta had invented an ingenious way of writing numbers in terms of the alphabet letters of Devanagri script of the Sanskrit language so that these could be incorporated in verse form. For example he mentions in one shaloka that as per his calculations, in one Mahayuga the sun revolves 43, 20,000 times around the earth, and the moon 5, 7756,336 times. In this duration earth rotates around its axes 1,58,22,37,500 times. However this technique of expressing numerals in terms of the letters of alphabets has a major drawback. A slight error in assigning letter to a numerical value can sometimes lead to a blunder! In spite of all this one cannot but appreciate the way in which Arya Bhatta had tried to express vast amount of information in a compact format. May be that one of the main reasons for this was the fact that those days writing material was scarce and not so easily available. (Those days people used to write on dried bark of trees with pens made of reeds.)

4. Main Contents of Aryabhatti

The first shloka of Aryabhatti is invocation to the Almighty God. In the second shaloka the author mentions his technique of expressing numbers in form of letters of alphabet of Devanagri script so that these can be expressed in form of words appearing in the shlokas. The first two shlokas have not been numbered. Next shaloka is numbered one. In this shaloka are mentioned the number of rotations of earth about its axis, as well as the number of revolutions of planets: Saturn, Jupiter, Mars, Venus and Mercury in a Mahayuga. It may be of interest to note that in this shaloka, Arya Bhatta mentions number of rotations of earth about its axis in a Mahayuga, implying there by that he was aware of the fact that earth rotates about its axis. (The figures in this shaloka are the average number of rotations of these bodies in a Mahayuga.) The maximum and minimum number of rotations that these heavenly bodies perform in a Mahayuga are then stated in the next shaloka. In the third shaloka it is mentioned as to how many Manvantras and Yugas are there in a single day of Brahma. It is also stated as to how many Yugas and Yugpads (parts of the current Yuga) had elapsed at the time of exile of Yudhistra on a Sunday. There is another novelty in this shaloka. Whereas so far the trend had been to assume different lengths of Sat Yuga, Treta Yuga, Dwapar Yuga and Kal Yuga in a Mahayuga, Aryabhatta assumes these to be of identical lengths and that in the present Maha Yuga, three Yug-pads (Sat Yuga, Treta Yuga and Dwapur Yuga) have elapsed, and the fourth Yug-pad (namely Kal Yuga) has already started.

In the next seven shalokas relationship between astronomical measures such as rashi, ansh, kala etc; the expanse and shape of the sky; the angular velocities of the sun, the moon and the earth; relationship between angul(finger), hath(hand) and purash(person), and yogan; diameters of earth, sun, moon and planets; retrograde and forward motions of planets; their extreme locations in the sky; smallest and longest time periods of their rotations, as well as the values of trigonometric ratios such as sine, cosine at differences of three ansh and forty five kalas have been given. Using his innovative technique of expressing numbers in terms of the letters of alphabet, Aryabhatta has been able to compress in just 10 shalokas a vast amount of vital information regarding astronomy.

In the next 30 shalokas, Arya Bhatta presents a lot of information about arithmetic, algebra and geometry. In fact he was perhaps the first scholar to include topics of mathematics in a book on astronomy. The topics discussed include problems on arithmetic, algebra and geometry. Using his unique style of expressing numbers as letters of alphabet, he could compress in just 30 shalokas what would have ordinarily required a book of big volume (and that too in such a way that a person with knowledge of high school mathematics can easily appreciate).

Next part of the book is titled Kalakriyapad. It is devoted to discussion on astronomy related topics. In the first two shalokas, the author explains relationship between time and angular measures. Next six shalokas are devoted to explaining different types of months and their relationship with year and yuga. A day of Brahma (called Kalap) is taken to consist of 1008 Mahayugas (this figure is slightly different from the length of the day of Brahma as 1000 Mahayugas as stated in Geeta and Manusmriti). In the ninth shaloka it is mentioned that the first half of a Yuga is known as 'Uttisarpani' and the second half 'Avasarpani' and these epochs commence on Chandrock (when the moon is at its highest position in the sky). However its significance is not very clear. In the tenth shaloka Arya Bhatta mentions his own date of birth. Next it is stated that the count of yuga, year, month and days in a month starts from Chaitrya Shukalpksha. In the next twenty shalokas, the average and the actual velocities of different planets are given.

Golapad is the last chapter of Aryabhatti. It has 50 shalokas. In the first shaloka the first point of Aries on the ecliptic is named as Meshadi. It is mentioned in this shaloka that starting with Meshadi up to the end of Kanya rashi, the sun remains in the northern hemisphere and from the start of Tula rashi to the end of Meena rashi, the sun remains in the southern hemisphere. In the next two shalokas it is stated how Paals (projections) of planets and the shadow of earth move along the ecliptic. In the fourth shaloka the distance from the sun to the moon and the planets mars, mercury etc are given. In the fifth shaloka it is stated that those halves of earth, planets and stars that face the sun shine by sun`s light whereas the other halves which are on the opposite side and do not face the sun remain dark (This of course is true in the case of the moon and the planets. However it is not true in the case of the stars which shine by their own light). In the sixth and seventh shaloka it is stated that the earth is surrounded by air and water on all sides. In the eighth shaloka it is mentioned that during the day of Brahma, the circumference of earth increases by one yogan (around 3 km). However it decreases by the same amount during the night of Brahma. In the ninth shaloka it is stated that just as stationary trees standing on the bank of a river appear to be moving backwards to a person seated in a boat moving along the river, in the same way from Lanka (a point on earth's equator) fixed stars appear moving west. However in the next (tenth} shaloka it is stated that it is because of the moving air that the stars seem to be revolving and the planets appear to be moving west and rising and setting. In the eleventh and twelfth shalokas, the shapes of the north and south poles are described. Names of four places on Vishvat (equator) which are each 90° apart are mentioned in shaloka thirteenth. In shaloka fourteen, distance between Ujjain and Lanka is given. (It helps in determining the latitude of Ujjain). In shaloka sixteen it is mentioned that because of its large size, less than half of the earth is visible from a place on its surface. In this shaloka it is also described as to how the earth appears to be rotating at its north and south poles. In shaloka seventeen, the length of days and nights of devtas, assurs, departed souls and human beings are mentioned. Shalokas eighteen to thirty four are related to geography. Rules for predicting solar and lunar eclipses are given in shalokas 37 to 47. In shaloka 48 a method for computing altitude of the sun at a given place at a given time is mentioned. It is also explained as to how the altitude of the moon can be determined and how using the positions of planets, moon and stars, position coordinates of planets can be determined. In shaloka 49 it is stated that how using intelligence, correct facts have been separated from the incorrect ones and presented in this book. In the concluding shaloka numbered fifty it is mentioned that the present Aryabhatti is similar to the original work of Swambhu of the hoary past and anyone who shows the audacity to criticize it will lose his reputation and shorten his life span.

In Aryabhatti, Arya Bhatta also mentions the order of occurrence of astronomical bodies in heaven. It is as under: beneath naxatras (stars) lie Saturn, Jupiter, Mars, Sun, Venus, Mercury and Moon. Beneath all of them lies the earth like a hitching peg in the midst of space. This of course is not true and was repudiated by later day astronomers such as Varahamihar.

Brief description of the main contents of Aryabhatti as given above shows that it not only encompasses basic essentials of astronomy as known at that time but also certain rules and formulae of higher mathematics some of which do not seem to be directly related to astronomy. It is of interest to note that there is no mention of tithis and naxatras and their names and locations. The term `Naxatra` at that time was used for stars in general. It is possible that astrology related topics might have been discussed by him in his second work which is not now available.

Panchangs prepared on the basis of Aryabhatti are even now acceptable to Vaishnavites of southern India. Brahma Gupta was a great appreciator of Arya Bhatta and his works. His work Khand-khadyak is based on Aryabhatti. Several commentaries on Aryabhatti have appeared in Sanskrit. In 1874 Dr.Karan also wrote a commentary on it in English.

08

PANCH SIDDHANTIKA OF VARAHAMIHIRA

1. Introduction

The development of mathematics based Siddhantic Astronomy came about in India as a result of interaction with astronomies of the west, particularly the Greek astronomy. This happened after the invasion of Alexander. Siddhanta literally means 'established fact'. There are eighteen traditional Siddhants namely: Angira, Atri, Bhrigu, Cyavana, Gargya, Kashyapa, Manu, Maria, Narda, Pitamah, Prashara, Poulisha, Romika (or Lomasha), Shaunaka, Surya (or Saura), Vasishtha, Yyasa and Yavana (Greek). According to Al-Baraouni, Paulisha Siddhanta was written by an Alexandrian named Paul, and Romika seems to codify the Roman astronomical knowledge.

After Aryabhattiya of Arya Bhatt, the next important work on astronomy is by Varahamihira. The work is titled 'Panch Siddhantika'. A specialty of this work is that this book does not present author`s own views on astronomy but instead presents his views on five alternative schools of astronomy that were in vogue those days. These are: Polish, Romik, Vasishtha, Surya and Pitamah Siddhantas. Out of these five, he attributes Polish and Romik Siddhantas to Laatdeva. According to Varahamihira, the Polish discipline of Astronomy is very clear and Romik discipline quite close to it. However out of the five, he considers Surya Siddhanta to be the most explicit and precise one. Regarding the remaining two, namely Vasishth and Pitamah Siddhantas, he does not have high opinion. Although the exact year of birth of Varahamihiar is not known, he died in 587 A.D. Base reference year used in Pittamah Siddhanta is 80 A.D. This indicates that perhaps Pittamah Siddhanta was composed around that period. Concepts of Pittamah Siddhanta also do not indicate substantial improvement upon the previously known astronomical concepts. That is perhaps why Varahamihira does not attach much importance to it and regards it to be a corrupted version of the known facts and so cannot be relied upon.

Panch Siddhanta written by Varahamihira has a special significance in Indian astronomy as it incorporates in a single volume five alternate astronomical disciplines prevalent at that time. Whereas some of these disciplines are much earlier than Varahamihira himself, some are to an extent his contemporary. This book was in oblivion for a long period. Prof. Booler, who had been deputed by the Government of Bombay Province of British India to look into certain available Sanskrit handwritten works which were gradually going into oblivion, chanced to get hold of its two copies. Dr. Thebo and Pandit Sudhakar Dewedi published its English translation along with original Sanskrit text and commentary by Thebo. Prof. Thebo also wrote a long preface to this book. Facts of this book being mentioned here are based on Dr. Thebo's commentary on its original Sanskrit version.

In Surya Siddhanta component of this book it is mentioned that the Sun God itself conveyed the information contained in this book to Mayasur who later conveyed it to others. It was a way of giving aura and authority to the contents of a book so that no one may easily comment on it or question correctness of its subject matter.

Varahamihira was a learned astronomer of his times. Had he desired he could have presented his own views on astronomy also in it. However he desisted from this and only presented the five well known astronomical disciplines in vogue those days.

2. Karan Granth:

Karan Granth is the title of the book in which Varahamihira describes the five alternative Siddhantas of astronomy prevalent at that time. The word `Karan Granth` literally means a manual of day to day working rules. It gives the reader convenient to use quick working rules for manipulating complex astronomical computations. These rules yield reasonably accurate (though not exact) results. On the contrary in Siddhantas precise rules for exact computations are given. These often involve complex computations but yield exact results. Such complex computations often take unduly long time particularly when these are performed manually. Moreover this Karan Granth does not deal with all the topics discussed in all the five Siddhantas. Several topics of the Siddhantas have not been dealt with in this Karan Granth.

3. Panch Sidhantika

Panch Sidhantika summarizes all the five Siddhantas namely: Pitamah, Vashisth, Romik, Polish and Surya Siddhantas. Varahamihira has himself ranked these five Siddhantas. He places Surya Siddhanta at the top followed by Romik and Polik Siddhantas which are assigned more or less equal rankings. According to him, remaining two namely Pittamah and Viashisth Siddhantas are relatively much inferior. The five Siddhantas have been presented in the book in that order. In the case of the contents of most of the chapters, there is not much doubt as to the Siddhanta on which it is based. There are however some chapters regarding the contents of which there is some ambiguity. It is likely that these chapters contain a mixture of the contents of more than one Siddhanta or these are Varahamihira`s own contributions.

We now discuss in brief the contents of each of these five Siddhantas as presented in Varahamihira`s Karan Granth.

4. Surya Siddhanta

Out of the five Siddhantas, Surya Siddhanta is the first to be summarized in this book. This Siddhanta is available independently also. A comparison of the two shows some major differences. It appears that the original Surya Siddhanta which was prevalent during Varahamihira`s times was later modified. Modifications were introduced to ensure that the values computed on the basis of the rules provided in the Siddhanta matched the actual observations. Surya Siddhanta was again modified later also (around one thousand years ago) to ensure the compatibility of the results computed on its basis with the actual observations. After careful scrutiny of its contents, Dr. Thebo and Sudhakar Diwedi were satisfied that Surya Siddhanta as presented in Karan Granth was the correct summary of the original Surya Siddhanta. As a consequence of this, they also felt that the other four Siddhantas summarized in the book must also be the correct versions of the corresponding original Siddhantas.

In Surya Siddhanta a method is given to calculate the starting epoch of Kalayuga. It can also be calculated using modern version of Surya Siddhanta. According to this, Kalayuga started in 3102 B.C. mid night of 17th-18th Feb. In this Siddhanta, the locations of sun, moon, mars, mercury, rahu and ketu at the beginning of Kalayuga are also mentioned. Based on this information, the location of these can be calculated at a desired moment. However since a long time has elapsed since the start of Kalayuga, computing the positions of different heavenly bodies taking the start of Kalayuga as the base involves quite complex and laborious computations. To overcome this difficulty, positions of different heavenly bodies at an epoch much closer to the period of this work are given in the Siddhanta so that these can then be used to calculate more conveniently their positions at desired time. This has been a practice in many of the later date works on astronomy also. Choice of the reference moment of time varied from author to author. It has been usually either the date of the start of the writing of that particular book or the date on which some important king or personality was born or ascended the throne. (Some people call a work Siddhanta only if it starts its computations from the beginning of time. Works which take the beginning of Kalayuga as the reference point are termed as 'Tantras'. Works which use as base an epoch of time different from the start of Kalayuga are not regarded Siddhantas or Tantras.)

5. Pittamah Siddhanta

Pittamah Siddhanta is presented in brief in chapter 12 of the book. This chapter has just five shalokas. Of these five shalokas, the first three state:

According to Pittamah Siddhanta, the length of a Yuga of sun and moon is five years. There is one adhimas (extra month) every thirty months and one tithi gets skipped every 62 days.

To determine Agrahan, subtract 2 from the Shaka year and divide the remainder by 5. This is Agrahan and it will start from the coming new moon.

If twenty eighth part of Agrahan is added to Agrahan, then the sum is the tithi. Again if Agrahan is multiplied with nine and product divided by one hundred and twenty two, the quotient is the Nakshatra of Surya (the sun). Again multiplying Agrahan with seven and then dividing the resulting product by six hundred and ten and then subtracting 'phal' from it yields the Nakshatra of the moon.

In an year the longest dinman is 18 mahurats and the smallest 12 mahurats.

6. Romik Siddhanta

In the fifteenth shaloka of the first chapter of Panch Siddhantika, there is a brief mention of the Yuga of Romik Siddhanta. This Yuga has also been called the Yuga of the sun and the moon. It has 2850 years in it. In this Yuga there are 1050 extra lunar months and 16547 missing tithis. If we divide Yuga by 150, then according to Romik Siddhata, each 19 years period has 7 extra months. These figures are exactly the same as were given by the astronomer Mayton in around 430 B.C. (almost a thousand years before Varahamihira). Writer of Romik Siddhanta preferred to regard a Yuga of 2850 years in place of conventional 19 years because he wanted not only the number of years and months in a Yuga to be whole numbers but the number of days also.

According to Romik Siddhanta, the length of an year comes to be 365 days, 5 hours, 55 minutes and 12 seconds. Whereas on the basis of present day more precise calculations, the length of an year is 365 days, 5 hours, 48 minutes and 46 seconds (a difference of 6 minutes and 26 seconds). The length of year in Romik Siddhanta is same as the length of an year in Greek astronomy of Hippochrus. Greek and Romik Siddhantas agree in some other ways also. However they are not identical and there are several differences.

In Panch Siddhantika, Shrishen has been mentioned as the author of Romik Siddhanta. However, according to Thebo, Shrishen does not seem to be the original author of Romik Siddhanta. He seems to have updated an earlier version of Romik Siddhanta developed by some earlier author. However even Brahama Gupta in his work `Suphut Siddhanta`, mentions Shrishen as the author of Romik Siddhanta at several places.

7. Polish Siddhanta

The shaloka in Panch Siddhantika where preparation of agrahan using Polish Siddhanta is discussed is so corrupted that Thebo and Suddhakar both failed to interpret it correctly with reasonable confidence. However in this shaloka figure 976 appears at some place. This seems to be the number of days after which an additional month (Adhimas) is to be added. Similarly figure 63 also appears. This seems to be the number of days after which a tithi is to be skipped. It seems that in Polish Siddhanta, longer periods have not been chosen to specify the addition of an `Adhimas` and skipping of a tithi. According Polish Siddhanta, the length of an year comes out to be 365 days, 6 hours, 12 minutes. Rules are also given in Polish Siddhanta for predicting eclipses. Directions of Yavanpur from Kashi and Ujjani are also mentioned.This points to Yavanpur being the present day Alexendria in Egypt.

Polish Siddhanta has also been mentioned by Bhattotpal in Varahamihira's commentary. It has also been mentioned by Prathudak Swami in his commentary on `Supphut Siddhanta` by Brahamagupta. However the work to which both these commentators refer is most likely some other version of Polish Siddhanta since in it a Mahayuga is mentioned to have exact number of years, months, days as well as the numbers of periods of rotation of other important planets. According to this, the length of an year comes out to be 365 days, 6 hours, 12 minutes and 36 seconds which is slightly different from the length of year as mentioned in Polish Siddhanta of Varahamihira.

Polish Siddhanta discussed briefly in Panch Siddhantika of Varahamihira was most probably written originally by a western astronomer. Albouroni (103 A.D) in his book on India mentions that Polish Siddhanta was originally propounded by a Polish who was most probably a resident of Alexendria in Egypt.

8. Vasishtha Siddhanta

Vasishtha Siddhanta has been described very briefly in Panch Siddhanta. It is similar to Pittamah Siddhanta. However it is more explicit and precise in certain matters as compared to other Siddhantas discussed in Panch Siddhnatika. Varahmihira himself regards Vasistha Siddhanta and Pittamah Siddhanta to be of a lower category compared to the other three Siddhantas. As in Pittamah Siddhanta, in Vasistha Siddhanta also it is assumed that when the duration of day time starts increasing, increase in the duration of day time is same each day. However this is not correct. Lengths of the smallest and the longest day as mentioned in Vasistha Siddhanta are different from those mentioned in Pittamah Siddhanta.

There is also a discussion on Rashis in Vasistha Siddhanta. Lagan is also mentioned.(Lagan is that part of the ecliptic which is in the eastern horizon at a given instant). However there is no mention of variable velocities of the sun and the moon that vary from day to day and their average velocities.

Saputik Siddhanta of Brahma Gupta also mentions Vasistha Siddhanta of Vishnu Chandra. However just as Shrishen has messed up Romik Siddhanta, in the same way Vishnu Chandra seems to have messed up Vasistha Siddhanta. Varahamihira mentions at one or two places that most likely Vasistha Siddhanta was compiled by Vijayanandan. A book on Vasistha Siddhanta is also currently available. However it does not seem to have any relationship with Vasistha Siddhanta as contained in Panch Siddhantika.

9. Triloki-Sansthan

Thirteenth chapter of Pancha Siddhantika is titled `Triloki-Sansthan`. It does not seem to be related to any matter discussed earlier in Siddhantas. Most likely it refers to the views of the author. In this chapter Varahamihira describes the possible creation of universe and certain other related matters.

In the first shaloka of this chapter it is stated that 'Earth is composed of five elements and is encased in a cage of stars in the same manner as a piece of iron is encased among magnets without touching any of these`. It is thus clear that Varahamihira was aware that the earth is not standing on any support and is surrounded by sky all around. He also mentions that just as plumes of flames rise upward from the surface of earth and a heavy object thrown from surface of earth returns back to the surface of the earth itself, similar things happen on the other side of the earth also.

However views of Varahamihira regarding the rotation of the earth are at variance with present day views on the subject. He writes 'Some persons believe that our earth is rotating. Had it been so then the birds flying in the sky would not have been able to return to their nests. Again if earth is rotating about its axis from west to east completing one rotation in a day, then flags on flag masts should have been stretched westward. If it is said that this rotation is very slow, then how is the earth able to complete one rotation in a single day`.

Even now some persons have such doubts. This is explained as follows: Suppose we throw a ball up inside the carriage of a moving train. Then it is observed to rise straight up and then fall straight down without being pulled in a direction opposite to that of the moving train. The reason is that all along its motion, the ball is sharing the velocity of the moving train in the horizontal direction. Ball appears to move vertically to a person sitting in the carriage of the train who is also sharing identical horizontal velocity of the train. Ball will not appear to be moving vertically to a person who is not traveling in the train.

He further mentions that Jains believe that there are two suns and two moons which alternatively appear in the sky. However Varahamihira did not subscribe to this hypothesis. Varahamihira was also aware of the exact reasons behind the waxing and the waning of the moon. He writes that on account of the motion of the moon, part of the moon getting illuminated by sun's rays and which is visible at a place on earth, changes from day to day.

10. Comparison of Five Siddhantas

On comparing the five Siddhantas which are briefly described in Panch Siddhantika, one is able to visualize as to how far the knowledge of astronomy had evolved in India by that time. Surya Siddhanta, Pittamah Siddhanta, Vedang Jyotish, Garg Sanhita, Surya Prajapati are essentially of the same category. In all these the length of a Yuga has been taken to be 5 years. Sun and other heavenly bodies are assumed to be moving with uniform angular velocities. Length of days in summer is assumed to increase at a uniform rate each day. Positions of the sun and the moon are generally stated with respect to the neighboring stars. Start of `Uttrayan` (when sun starts shifting north wards from its extreme southern most position in the sky in the horizon at the time of its rising) has been taken to be the epoch when the sun enters Ghanishtha Naxatra.

In Pittamah Siddhanta a few salient features of the earlier works on astronomy have been also incorporated. The word Yuga appears in all these works. Gradually length of a Yuga started to be taken larger and larger. However no one repudiated the original length of 5 years for a Yuga. Second common feature is the use of tithis which is prevalent in Indian astronomy till date. Tithis have been used nowhere else in the world for recording the passage of time.

Vashishth Siddhanta appears to be more evolved than Pittamah Siddhanta. However even this is much inferior to Surya Siddhanta. Remaining three Siddhantas, namely Polish, Romik and Surya Siddhanta are regarded to be of the same level. In all these there is reference to the actual positions of the sun and the moon assuming these to be moving with their actual velocities which are not uniform and vary periodically with time. It is also mentioned that at a given instant how much their actual angular velocities differ from their mean velocities. Surya Siddhanta is more specific and precise in comparison to the other two. Compared to Polish and Romik Siddhanta, rules for predicting eclipses are more precise and accurate in Surya Siddhanta,

Varahamihira was aware that the summer solstice happens in the middle of Ashlekha Naxatra. However there is nothing to support that he was also aware of the fact that Gamma, the first point of Aries (where equator and ecliptic cross each other and where the sun is around 21 March each year), gradually recedes backwards along the ecliptic.

11. Astronomical Instruments in Use

There were no sophisticated astronomical instruments in use at the time of Varahamihira. Varahamihira did not feel the necessity of describing all the instruments in use. Pole (vertical and inclined), Unattansh Mapik, Jal-Ghati and Chedak Yantrani were the commonly used astronomical instruments. It is mentioned that while describing commonly used astronomical instruments and discussing their method of use 'Guru should impart the knowledge about construction and use of astronomical instruments to only a few exceptionally intelligent pupils. Pupils after learning techniques for construction and use of these instruments should construct them in such a way that even their progeny does not become aware of it!

Pole was a simple instrument frequently used to determine directions of stars. It is mentioned that after placing eye at the base of a pole, it should be first held in vertical position, and then the pole be so rotated about the base that the eye, the tip of the pole and the pole star come in the same straight line. Then perpendicular drawn from the upper end of the pole on horizontal surface through its base is a measure of the sine of the angle that the pole star is making with horizontal. The radius and circumference of the earth can be determined in the same way as the taste of the salt is known by tasting salt water! Later on Bhasmar Acharya named such a pole as 'Yashti Yantra'.

Another astronomical instrument mentioned is 'Uttansh Mapik'. This instrument is circular in shape and is divided into 360 equal parts. Its radius is 'one hast' and thickness 'half a finger'. There is a hole in it. At noon the rays of the sun after entering this hole fall on the inner side of this circular ring. The angle which this ray of light makes with a vertical thread passing through the centre is the measure of deviation of the position of the sun from the vertical.

Third instrument called Jal-Ghati was used to measure the passage of time. This consists of a semi-spherical vessel with a finely calibrated hole at its base. It is placed in a bigger vessel containing water. Water gradually enters the inner vessel through the hole in its base. When it gets completely filled with water, it is a measure of one 'Nadika' of time. The hole at the bottom was so calibrated with respect to the volume of this inner vessel that it got filled with water exactly 60 times during one complete day and night period.

12. About the Author

Varahamihira mentions his place of residence as Avanti. He mentions the name of his father to be Aditya Yyas. He died in 587 A.D. Varahamihira seems to have more fascination for astrology than astronomy. He has also written a voluminous book titled 'Briha Sanhita' on astrology. His two other works 'Brahijatak' and 'Yog Yatra' are related to astrology. 'Pancha Siddhantika' is his only work on mathematical and observational astronomy. Al Borouni speaks highly of him in his book 'Bharat Varsh'. In Sanskrit literature also his name appears among the nine 'Ratnas' of Vikramaditya. These also include Kalidasa. However these nine names do not seem to be contemporary.

13. Period of Panch Siddhantika

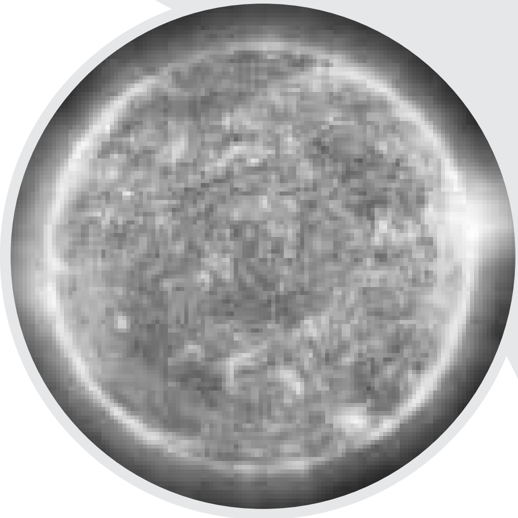
In Romik Siddhanta of Panch Siddhantika, it is stated that for preparing Agrahan 427 be subtracted from the current Saka era year. It thus appears that all calculation in Romik Siddhanta are for the saka year 427. It is therefore felt that perhaps the period around Saka year 427 was the period in which Varahamihira wrote Panch Siddhantika. Al Bburoni also accepts this as the period of Panch Siddhantika. Dr. Karan is of the view that Saka year 427 was perhaps the year of birth of Varahamihira himself. This year corresponds to the year 505A.D. Varahamihira is believed to have died in the Saka year 509 (corresponding to year 591 A.D.). It may be noted that Aryabhatta was born in the Saka year 398 and composed his Aryabhatti in the Saka year 421. Name of Aryabhatti appears in Panch Siddhantika so it is definite that Panch Siddhantika was composed after the Saka year 421.

A question naturally arises as to why Saka year 427 was chosen as reference year in Romik Siddhanta. Was it composed in this year itself or earlier? According to available evidence there is sufficient reason to believe that Romik Siddhanta was composed much earlier than the Saka year 427 and it was Varahamihira who while including it in his Panch siddhantika chose Saka year 427 as the reference year for computations.

14. Influence of Western Astronomies

Names Polish and Romik Siddhantas that appear in Pancha Siddhantika, themselves suggest that these Siddhantas did not originate in India but in the west. In one of these Siddhantas computations are with respect to location 'Yaumoutra' of Yavanpur. In the second of these Siddhantas, the direction from Yavanpur to Ujjain is mentioned. Both the Siddhantas have some material which is not there in Vedang Jyotish, or Pittamah or Vasishth Siddhantas. This gives credence to the fact that by the time of Varahamihira, Indian astronomy was getting influenced by the western astronomies. However it is difficult to pinpoint a particular individual or a book which was the primary source of this information. It appears that the information about western astronomy started coming to India after Hippochrus but before Potlmey. Most likely it was not in one lot but it trickled bit by bit. As Indian astronomers became aware of the new facts that were known to the western astronomers, these facts were suitably modified and assimilated in Indian texts on astronpmy.

After Varahamihira, the next important astronomer on record is Brahma Gupta who was born in 598 A.D. His works on astronomy 'Brahmasphut Siddhanta' and 'Khankhadiyak' are available even now. In the year 1150 A.D. Bhaskar Acharya wrote 'Siddhanta Shiromani'. After that no original astronomical work of significance appeared in Indian astronomy.



09

SURYA SIDDHANTA

1. Intoduction

Varahamihira had summarized five different astronomical Siddhants in his book 'Panch Siddhantika'. One of these five Siddhantas was Surya Siddhanta and it had been considered the best amongst the five. Surya Siddhanta is available even now. However there are several major differences in the contents of the currently available Surya Siddhanta and Surya Siddhanta of Varahamihira. It appears that from time to time, as and when new facts emerged, corrections and updates in the contents of Surya Siddhanta were being made. What is being summarized in this chapter is the information as it is contained in the present day version of the Surya Siddhanta.

2. Writer of Surya Siddhanta

Nothing definite can be said about the original author of Surya Siddhanta. As in the case of Vedas and Upnishads, the name of the writer is not mentioned. After invoking the blessings of the Almighty, it is mentioned that the facts being presented in this book have been directly conveyed to the author by the Sun God (Suriya Devta). This was perhaps a tradition in the past to accord aura and authority to a written work so that no one had the audacity to challenge the correctness and authenticity of the stated facts. It is also mentioned in it that just as there are eighteen Puranas, simlarly there are also eighteen Jyotish Siddhantas (astronomical principles), which are named after eminent sages of the yore. However with the passage of time most of these Siddhantas have gone into oblivion (or may be these could not stand the test of times as new facts came to light).

3. Units of Measure used in Surya Siddhanta

Different units of measure used in Surya Siddhanta are briefly summarized as under:

Units of time: Eleventh and 12th shaloka of Surya Siddhanta describe the units for measure of the passage of time. According to these:

> 10 Gurvakshar = One Prana, 10 Paranas = One Vinadi, 60 Vinadis = One nadi, and 60 nadis = one day.

Nadi has also been called Nadika or Ghatika. It is a bit strange as to how these small units of time were being measured in the past as the only time measuring instrument mentioned by Varahamihira is nadika consisting of a pot with a fine hole at its bottom placed in a tub of water.

After this description of the basic units of time, there is description of the larger units for measure of time. A month and an year have been defined. One year has been called one day of Devtas (gods). Three hundred and sixty days of Devtas constitute one year of Devtas, and twelve thousand years of Devtas constitute a Chaturyug. Seventy one Chaturyugs constitute one Manvantra. Afer each Manvantra there is an evening of duration equivalent to the length of Satyayuga. Again fourteen Manvantras constitute one Kalpa.

Length of a Kalpa including initial sandhya is 4,32,00,00,000 years. Moving further, one Kalpa is one day of Brahma and 360 days of Brahma make one year of Brahma and the age of Brahma is up to 100 years! Age of Brahma has also been called 'Par' and half of it 'Praradh'.

In Surya Siddhanta, the count of the passage of time stops with the age of Brahma. However in Vishnu Purana there is mention of even a still larger unit of time. In this unit two Prardhas constitute a day of Vishnu and even still bigger units of the measure of time have been mentioned.

However according to Surya Siddhanta, the age of Brahma is 31,10,40,00,00,00,000 human years! It is doubtful if such small and such large units for the measure of the passage of time were of any practical use. These might have been visualized for convenience in computations to avoid the use of fractions. (Indians of the past were not very adept in dealing with fractions.)

After mentioning these units for the measure of time, the Manvantra and Yuga of the epoch in which Surya Siddhanta was compiled is mentioned. It is also mentioned as to how much time it took for the creation of the universe. Another statement made there is that the average angular velocities of all the planets are identical. (However that is not so as per our present day knowledge).

Units of angular measure: Units of angular measures have been given next. These are:

> 60 Vikaran=10 Kala, 60 Kala=1 Bhag(or Ansh), 60 Bhag (or Ansh)=1 Rashi, and 12 Rashis=1 Bhgan (i.e complete revolution).

Speeds of Planets: Next the average angular velocities of different planets have been given. The number of revolutions which Sun and the planets such as Mercury make in one Mahayuga (which is 1/100 of Kalpa) is given. It is mentioned that in a Mahayuga,sun makes 43 lacs and 27 thousnad revolutions, Mars 22 lacs and 26 thousand and eight hundred revolutions and so on.

4. Karan Granths

In the west the convention has been to indicate the position of a planet and its velocity at a specified moment. These are then used to compute the position of the planet at a desired moment. Astronomical works in India which make use of this technique have been called 'Karan Granths' and these have been usually held in lesser esteem compared to 'Siddhantas'. According to Surya Siddhanta, initially all the planets were at the start of Megha Rashi. (In fact computations show that this was the case at the beginning of Kalayuga).

By consensus this epoch is assumed to have occurred at the midnight in Ujjaini between the nights of 17th and 18th February in the year 3102 B.C. (However modern day computations show that the sun, the moon and the planets were not exactly at the same position at that instant). It seems that the author of Surya Siddhanta through his calculations determined an epoch of time when Sun, Moon and all planets could be at identical positions and termed it as the beginning of Kalayuga. However there is no mention of such an epoch in Vedas or Puranas or Vedang Jyotish.

5. Beej Sanskar

Surya Siddhanta is the basis of formulation of many panchangs even now. However in view of the errors in the assumed velocities of the planets (which have been assumed uniform), it has started producing errors of as much as 9 to 10 degrees in the actual and computed positions of planets. Computations based on the original Surya Siddhanta result in even still larger errors. After a few hundred years, the differences in the computed and observed positions of the planets became apparent. That is perhaps why in order to adjust this difference, the later period writers of Surya Siddhanta introduced a correction rule called 'Beej Sanskar'. This rule essentially modifies original velocities of the sun, the moon and the planets to an extent that their new obtained positions are quite close to the observed positions. This happened most likely around 16th century A.D. It has reduced errors in the computed and observed positions of the Sun, the moon and the planets to an extent that at present this error is rarely more than one or two hours.

Brijesh prepared a table in which he compared the periods of revolutions of the Sun and the Moon as per the present day Surya Siddhanta, Siddhanta Shiromani, Tolomy as well as on the basis of modern computations. According to this table, as per Surya Siddhanta the time period of revolution of the sun is 365 days, 6 hours, 12 minutes and 36.6 seconds and of the moon 27 days, 7 hours, 43 minutes and 2.6 seconds. However these figures are respectively 365 days, 6 hours, one minute and 10.8 seconds for the Sun and 26 days, 7 hours, 43 minutes and 11.4 seconds for the moon as per latest computations. Difference is obviously not very significant. However this difference is much greater in the case of calculations based on other Siddhantas.

It is also mentioned as to how many revolutions the nodes of the Sun, the Moon and other planets make in a Yuga. Number of revolutions that moon and planets make in a Mahayuga is also given.

6. Mandoch and Paat Points

The Sun, the Moon and the planets do not move with uniform angular velocities. Their angular velocities keep on increasing and decreasing periodically. The point where the angular velocity of such a heavenly body is the least is called its Mandoch and the point on the orbit where it is the largest is called its Sheahroch. More over halves of the orbits of the moon and the planets are above the ecliptic (the orbit of the sun in the sky) towards north and the other halves below the ecliptic towards south. The points where the orbits of the moon and the planets cross ecliptic are called Paats (nodes, one ascending node where moon or planet comes to the northern side of the ecliptic and the other descending node where it goes down to the southern side of the ecliptic).

According to Surya Siddhanta, Mandoch of the Sun keeps on shifting gradually east making 387 revolutions of the ecliptic in a Kalpa of 4,32,00,00,000 years. This is in fact 1/600 of the actual value. Mandoch of the orbit of the moon is also in motion. However its speed is so slow that it is as good as assuming it to be stationary. That is perhaps why authors of various Siddhantas assume Mandochs to be stationary.

6.1 How was the Speed of Mandoch Computed

It is in fact very difficult to compute the speeds of Mandochs. It needs very elaborate and precise measurements spread over large periods of time. How was that possible in the ancient past? Bhaskaracharya who was born in 114 A.D. regarded this task to be well nigh impossible. Some scholars are of the view that perhaps their values came to India from abroad and were later suitably modified and adjusted by the Indians astronomers. There are reasonable indications to suggest that many of the facts mentioned in the present day Surya Siddhanta have been borrowed from abroad. However it may be noted that many of the later day corrected values in Surya Siddhanta are superior to even those given in Tolomy.

An interesting fact worth nothing is that the long periods of Yuga, Maha Yuga etc indicate that Indians even in the past believed that earth and universe had been there for millions and millions of years and will be there for a very long time to come. This is unlike belief of Western religions most of which till recently believed that this universe had been created in a not very distant past, in fact only a few centuries ago.

7. Ahargan or Agrahan

In the next three shalokas of Surya Siddhanta, it is explained as to how starting from the time of the start of the universe, the number of days that have elapsed till present moment can be determined. This count of the total number of days elapsed has been called 'Dhivgan' or 'Dinrashi'. The same has also been termed 'Ahargan'. This is a very large number. For instance on the Basant Panchmi (Magh five) of Vikrami year 1974, it was 7,14,40,41,31,603. This number is helpful in Karan Granths which instead of starting count from the origin of the universe, start count from the start of a nearby epoch usually the start of Kalayuga.

Next the methods for determining the day of the week and Varshpati (lord of the year) and Maspati (lord of the month) are given. Varshpati and Maspati are from amongst the sun, moon and planets. These are not very essential for day to day work.

Techniques for determining the average angular velocities of planets are next given. Knowing their positions at the beginning of Kalayuga and the number of Bhaguns in a Yuga, simple arithmetic calculations yield their current positions. Rules for determining Paat and Mandooch are also given. In the fifty sixth shaloka it is mentioned that assuming the beginning of universe as the origin unnecessarily complicates calculations. It is therefore better to make use of above given rules to shift the origin to a nearby important epoch such as the start of Kalayuga.

8. Dimensions of the Earth

In the next part of Surya Siddhanta, the dimensions of the earth are mentioned. Its diameter is given to be 800 Yojan. To determine its circumference multiplication of this diameter with $\sqrt{10}$ has been proposed. (Actually circumference is л times the diameter and the value of л is 3.1416 where as the value of $\sqrt{10}$ is 3.162. This results in an error of less than 1% (about 2/3%)). Technique for determining the circumference at a parallel of latitude is also mentioned and it is perfectly correct.

Parallel of Latitude which passes through Ujjain is taken as the reference latitude. It is mentioned that Rohitak (most probably the present day Rohtak in Haryana) is also on this parallel of latitude. In the next three shalokas method for determining the longitude of a place is given. This method makes use of the time at the beginning and end of a solar or lunar eclipse.

9. Sapstadhikar

The first chapter of Spastadhikar is titled Madhyamidhikar. In this chapter those positions of the sun, the moon and the planets are given which they would have occupied had they been moving with their average uniform angular velocities. The fastest and the slowest speeds of these heavenly objeects are also mentioned.

Trigonometric tables are given in the next three shalokas and these are reasonably accurate. Sines of angles at intervals of three (va'k) are given in the tables. It is also explained as to how (when needed) sines at angles other than those as given in the tables can be calculated using tabulated values. It is also explained as to how keeping in view the definitions of trigonometric functions these tables can be easily prepared. In view of these trigonometric tables, Brijesh is of the view that trigonometric tables must be having their origin in India.

In the next shaloka the maximum angular velocity of the sun is given. It is also explained as to how its velocity at other epochs can be computed. In shaloka twenty nine, techniques for computing मन्दोच्च्र, षीघ्र, केन्द्र, पद्र, भुज्जया, कोटी are given. The word (केन्द्र) does not seem to be a Sanskrit word as it has not been used earlier in the Indian Literature. According to Brijesh this word is a derivation from the Greek word 'Krenton' for the centre.

In shaloka 34 and the subsequent ones, it is explained as to how the exact locations of the sun, the moon, and the planets such as mars etc can be determined. A comparison of the techniques given in Surya Siddhanta for computing the location of the sun, moon etc at a given instant of time with corresponding techniques of Tolomy shows that where as the methods of Tolomy yield more accurate results, techniques of Surya Siddhanta are comparatively simple to use and are robust. In fact these are more convenient than even the techniques currently in use for this purpose. (For computing time and duration of lunar and solar eclipses, it is essential to know their exact locations , and how these change with passage of time.)

It is also mentioned in Surya Siddhanta that the orbit of the moon about earth is not fixed. Moreover it is tilted more on one side, and the centre of this orbit shifts to the other side of the planet earth as moon reaches the lowest position in its orbit.

Besides giving techniques for computations of the positions of planets at a given time, methods for computing the Tithi on a particular day are also given. This is next followed by the count of Karans.

10. Triprashnadhikar

In this part of Surya Siddhanta, three topics have been discussed. These are: Disha (direction), Desh (location) and Kal (time). For this first a method for setting of a cone (षंकू) is explained. (Unfortunately one does not find much discussion about observational instruments in works on Indian astronomy.) षंकू (Cone) had been a popular observational instrument in use. (It finds mention elsewhere also.) Shalokas 5 to 8 define some terms related to the shadow of the cone. In shalokas 9 and 10 an important fact is mentioned that in a Yuga, the orbit of a planet tilts six hundred times towards the east. After multiplying this number 600 with इष्ट अहर्गण and dividing result by sawan days whatever is obtained make भुज (Bhuj) with it. Now multiply it with three and divide by ten. This results in अपनांष. Adding it to the position of sun, moon, mars and other planets their क्रान्ति,छाया,चरदल (speed) etc can be obtained.

A method to compute Ayan (Precession) is given in another shaloka. According to Surya Siddhanta विषुव (the first point of Aries) moves 54 ayansh in an year. Computations show that this must have been 50 विकला at that time. It is bit surprising as to what instruments were used to achieve such accuracy. It was the Greek astronomer Hipochrus who discovered it. He also stated that its value cannot be less than 36 विकला per year. Tolomy accepted this value instead of improving it. Western astronomers are a bit surprised as to how the astronomers in India could come up with such an accurate value in the distant past. Some even suspect that it was perhaps just by chance.

Retrograde motion of the First Point of Aries: Gamma, the first point of star cluster Aries, is regarded as the point where ecliptic crosses equator. This point slowly recedes backwards along the ecliptic making on complete revolution in around 26,000 years. This is known as slow backward (retrograde) motion of Gamma along the ecliptic. There is mention of this recession of equinox called Aayan in the latest version of Surya Siddhanta. However there are differences of opinions as to whether this also finds mention in the original Surya Siddhanta as summarized by Varahmhira in Panch Siddhantika. Brahma Gupta who succeeded Varahmhira by several years makes no mention of this in his treatise on Suriya Siddhanta. It thus seems that Aayan did not find mention in the original version of Surya Siddhanta.

Topics related to the shadow of a flag staff (षंकू) are discussed in the first eight shaloka. These are again discussed in shalokas eleven onwards. Shalokas 9 and 10 are related to Aayan. It appears as if these two shalokas on Aayan are a later date entry. In his work titled Siddhanta Shiromani, Bhaskracharya mentions that the spring equinox is moving uniformly in one direction. However the contemporary commentators of his work did not agree with it. They believed that its position oscillates about a central position. This incorrect hypothesis regarding the oscillatory behavior of spring equinox gradually travelled from India to the west through Arabs.

Shadow of a Flag Staff: In the eleventh shaloka the length of the shadow of a flag staff at noon is discussed. In the next few shalokas method for computing the latitude of a place using this shadow is given. Next it is shown how the shadow of a flag staff at noon can also be used to measure क्रान्ति of the sun which can then be used to compute position coordinates of the sun at that moment. In the ensuing shalokas, several other shadow related problems as well as their practical uses in observational astronomy have been discussed. In the forty first shaloka a method for computing the path of the tip of the shadow of the staff, assuming this path to be a circle, is given. (However the assumption that this path is a circle is not correct.)

Next it is explained as to how the times of rising of different rashis at a particular place as well as in Lanka can be calculated. (This Lanka is not the present day Shri Lanka. It is an assumed point on the equator where longitude passing through Ujjain crosses the equator.) Method for computing Lagan has been also given. (Lagan is the point of the ecliptic which is in the eastern horizon at a given moment.)

11. Chandra Grahanadhikar

Fourth chapter of Surya Siddhanta is titled Chandra Grahandhikar. In the first shaloka of this chapter the diameter of the sun is stated to be 6500 Yojan and that of the moon 480 Yojan. The diameter of the earth is stated to be 1600 Yojan. Thus according to Surya Siddhanta, the diameter of the moon is around .33 of the diameter of earth. However as per our present day computations, it is around .27 of the diameter of the earth. Thus the diameter of the moon as compared to the diameter of the earth as given in Surya Siddhanta is not too much in error. However there is great error in the value of the diameter of sun which is stated to be just around four times the diameter of earth. In reality it is much bigger. In fact if sun is imagined to be the size of a football, then the earth is just a dust particle! (By the way, the diameters of the sun and moon were computed using the premise that the heavenly bodies such as the sun, the moon and planets move around the earth with identical uniform angular velocities, and this is not correct.)

In order to determine the diameter of the sun and the moon, it is essential to know their distances from the earth. Methods for measuring these distances are not mentioned explicitly in Surya Siddhanta. These also seem to have been calculated under the incorrect premise that these heavenly bodies are moving around the earth with identical uniform angular velocities.. As a consequence the computed distances are incorrect.

Angle which a semi- diameter of the earth subtends at the moon is called (लम्बन) of the moon. Because the distance of the moon from the earth keeps on changing periodically, the value of this lamban also changes periodically. According to modern calculations, its average value is 57 Kala and it varies between 54 and 61 kalas. In Surya Siddhanta it is taken to be 53 1/3 kalas. Hippochrus calculated its value as 57 kalas and this is also reasonably accurate. However even the calculations of Hippochrus regarding the distance and the diameter of the sun, are in error. Hippochrus has taken the Lamban of sun as 3 kalas, whereas as per Surya Siddhanta it is 4 kalas. However its true value is just 1/7 kalas!

Next the techniques for computing angular diameters of the sun and the moon are explained. The size of the shadow of the earth on the orbit of the moon is given next. It is only when moon enters such a shadow part of the orbit that a lunar eclipse occurs. The statement that during an eclipse, the moon is devoured by demon Rahu or Ketu is just a crude way of explaining this phenomenon to common people. The writer of Surya Siddhanta was aware of the true cause of the eclipses and he could compute with reasonable accuracy the time and duration of their occurrence as well as the portion of the moon that would get eclipsed and that whether it will be a partial or a full eclipse

12. Surya Grahanadhikar

This chapter is devoted to solar eclipses. Techniques for computing the time of the start of a solar eclipse, its duration and whether it will be full, partial or annular at a given place are also given. It is a voluminous chapter giving minutest details of the relevant computations.

13.Parilekhadhikar

This is the sixth chapter of Surya Siddhanta. Some publications have given it the title 'Chedhkadhikar'. Both mean the same. What is contained in this chapter is mentioned in the first shaloka of this chapter. It is mentioned that without chedhak it is not possible to tell at what point of its disc, an eclipse of the sun or moon will commence and end. Keeping this in view the 24 shalokas contained in this chapter are devoted to explaining the technique for the construction of a chedhak.

14. Grahyutiyadhikar and Naxatra Grahyautiyadhikar

These are the titles of seventh and eighth chapters respectively. In chapter seven it is explained as to when two planets or a planet and a star come close to each other. It is also mentioned that after a planet or a star gets very close to the sun, it disappears from the view and is said to have become Grasth.In eighth chapter titled Naxatra Grahyautiyadhikar, matters related to coming closer to each other of various stars and planets are discussed. In fact this chapter has just two shalokas and for detailed computations regarding this, the reader is referred back to chapter 7.

15. Position Coordinates of Stars

Modern astronomy makes use of three systems of coordinates to fix the position of a heavenly body. Each system is with reference to a chosen base great circle. A point on this circle is chosen as the origin and the coordinates of a point on the celestial sphere are taken to be the angles which are subtended at the centre of celestial sphere (the observer himself) by the arc length drawn from the star perpendicular to the reference circle, and the arc length from the chosen origin on the reference circle to the foot of the perpendicular on the reference circle . The three great circles chosen as reference circle are: the ecliptic, the equator and the horizon. Methods are also available for converting from one system of coordinates to another. In Surya Siddhanta and other Indian astronomical literature, the ecliptic has been generally chosen as the reference circle. However it is no where made clear as to how these coordinates were actually measured. The instrument used for this purpose is named Golank and techniques for constructing a Golank are also mentioned. However this instrument cannot provide precise values of the coordinates (upto 10th of a kala) as reported in literature. It seems that perhaps help was being taken of theoretical computations for refining the coordinates obtained using the values obtained with the Golank as the initial estimates.

16. Yog Stars

The path traced by the sun among the stars on the celestial sphere in its annual revolution around the earth is called ecliptic. This ecliptic has been divided into 27 more or less equal parts and each part has been called a Rashi. Each Rashi has been assigned a name which is usually the name of the important star cluster in that part of the ecliptic. In Surya Siddhanta, the most important star in each of these star clusters (usually the brightest star) has been given the name of the Rashi in which it is located and called its Yog star. In Surya Siddhanta it is mentioned as to how far is the Yog star of a particular Rashi from the starting point of that Rashi. Positions co- ordinates of Yog stars and other well known stars are also given in Surya Siddhanta.

17. Other Chapters

Ninth chapter of Surya Siddhanta is titled Udyastadhikar. In this chapter it is mentioned that when a star or a planet gets closer to the sun, it disappears and again reappears on the other side. It is also mentioned that the stars Abhijit, Brahmahridya, Swati, Shreshtha and Uttra- Bhadrapad are very far from the ecliptic towards the north and so never get covered by the Sun.

In the next chapter the times and positions of rising and setting of the moon each day are given. The name given to this chapter is Shranghontra Adhikar. It has also been mentioned in this chapter that the moon is not visible as long as it is within 12 ansh of the sun. Methods for computing locations of its edge ends are also given.

Chapter eleven is titled 'Patadhikar'. The word `pat` is generally used in the sense of distress. When Kritis of the sun and moon become equal then regarding it as a distress of greater magnitude, it has been named `Yuatipati` (greater distress). It is also explained as to how computations need be made for such occasions.

The next chapter has been given the title 'Bhugoladhiya'. Answers to questions asked in the first few shalokas are given in the subsequent shalokas of this chapter. A peculiarity of this chapter is that instead of its being titled 'Adhikar', it has been titled Adhyay, an appropriate Sanskrit/ Hindi word for a chapter. The same is true in the case of next two chapters also.

After this Mayasur pays obeisance to 'Paurash' born out of the sun and asks with folded hands: " O` Lord, what is the future of this earth? On what is it resting? How many parts does it have? How are the seven petals resting in it? How does the sun manage 'Aahoratra' and how it revolves around the earth illuminating all the four Bhavans? Why are the days and nights opposite of each other in the domains of Devtas and Assurs and how it happens in each revolution of the earth? Why the duration of day and night is of one month in the case of Pitras and 60 Gharis (24 hours) in the case of humans? Why the days and nights are not identical every where? How do the stars and the planets rotate and what is the basis of it? The orbits of rotation of the stars and planets are how much above the earth and what are the distances amongst different heavenly bodies? Why the magnitude of brightness is different for different stars? Why the sun rays are hot and piercing in summer but not so in the winter? How far the rays of light can go? How far the rays of light of the sun and moon go and what conclusions can one draw from it." After listening to these queries Surya Devta narrates the contents of the next two chapters and asks Mayasur to listen to these answers carefully.

Not only have the above questions been answered but in addition to this, the story of universe has been also narrated. This narrative is an intermix of the description about universe as given in Vedanta, Sankhya and Shrimad Bhagvat. The answers given to the queries of Mayasur are explicit, straight forward and easy to comprehend. Here we present a few for illustration.

Those who live on the surface of a sphere always feel that they are on the top of it and there are some persons elsewhere on the sphere who are down below. For example persons living in Bharatvarsha imagine that the persons living in Ketuma are down below, and persons living in Lanka imagine that persons living in Siddpur are living below them. In fact persons everywhere on earth feel that they are at the top. It is so because the earth is a sphere in space and has no up or down.

The thirteenth chapter of Surya Siddhanta is titled Jyotish-upnishad-adhya. In this chapter techniques for constructing astronomical instruments in use at that time are given. However the description is very brief and sketchy. It is not easy to construct these instruments based on these descriptions. The instruments mentioned are essentially a self revolving sphere to mimic motion of celestial sphere, shanku and a pot with a hole in its bottom to measure the passage of time.

The last chapter of Surya Siddhanta is titled 'Manadhiyaya'. In this chapter there is description of different units for measuring time such as Saur, Savan, Tithis, Paksh (Shukul and Krishna).The names of months have also been mentioned. In the concluding two shalokas of this chapter, it is mentioned as to how the Rishis learnt this knowledge of astronomy from Maaya.

18. Period of Surya Siddhanta

In the later date Surya Siddhant complied by Ranganathan there are exactly 500 shalokas. He has also written a commentary on it. It appears that at places he has added some new shalokas to the original Surya Siddhanta and at some places he has omitted shalokas of the original Surya Siddhanta. This revised version by Ranganathan was composed in the eleventh century A.D. The original version seems to have been composed in fourth century A.D. A comparison of the positions of Rashis and Naxatras as given in the original version and their positions as mentioned in the revised version and their current present day positions support these dates.

Al` Borouni wrote a book on India several years after the compilation of original Surya Siddhanta. He mentioned Lat Dev as its author. However it does not seem to be correct. Varahamihira has mentioned Lat Dev as author of Romik and Polish Siddhantas. In fact Lat Dev was a student of Arya Bhatt-I. If it had been known that Lat Dev was also the author of Surya Siddhanta, then Varahamhira would have mentioned this also in his Panch Siddhantika.

From its very inception, Surya Siddhanta has generally been regarded superior to other Siddhnatas.. With the passage of time as the differences between the computed and observed positions started getting larger and larger, astronomers from time to time have been making suitable corrections in the data values to ensure that these are not far from the actual observed values and these are relevant for the current time period. However the basic fundamentals were left untouched.

Surya Siddhanta has been regarded as the words spoken by the Sun God himself and so its contents can not be questioned. This has perhaps been the reason for their not being discarded or suitably modified by later day astronomers. Surya Siddhanta version that has reached us discusses planetary mean motion, planetary true motion, eclipses of the sun and the moon, time related measurements and certain other aspects of astronomical significance. It also discusses the precession of equinoxes and mentions its value to be 54 seconds of arc per year (close to actual value of 50.2 arc seconds). However this motion of equinox is incorrectly regarded as oscillatory back and forth.

10

VARAHAMIHIRA TO BHASKAR ACHARYA-II

1. Intoduction

Astronomers of repute had been appearing on the horizon of Indian astronomy from time to time. For instance Varahamihira mentions in his Panch Siddhantika that Lot Dev was the writer of Polish and Romik Siddhantas. Braham Gupta also mentions at several places in his works the names of astronomers such as Shrishen, Vishnu Chandra and Vijay Anand. It appears that these astronomers generally did not make any original contribution of their own but mostly compiled and updated earlier available works on astronomy. The time period of these astronomers is around 562 to 665 A.D. Based on the works of these astronomers, Vishnu Chandra wrote Vasishtha. In the present chapter we mention briefly certain astronomers of reasonable repute who appeared on the horizon of Indian astronomy in the period from Varahamihira to Bhaskaracharya II.

2. Astronomers from Varamihira to Bhaskar Acharya-II

Bhaskaracharya-I (629CE): Two hand written manuscripts of Bhaskarachary-I namely ‘Mahabhaskariya’(great book of Bhaskar) and Laghubhaskariya (small book of Bhaskar) are available in manuscripts library of Madras(now Chennai) as well as in Curator’s office library in Trivandrum (now Trivanantpuram, Kerala). Both of these books are based on astronomical findings of Arya Bhatta. Their author, Bhaskar, is different from the well known

Bhaskar Acharya (author of Leelavatti etc) who came later. In order to distinguish the two we shall call the present Bhaskar Acharya as Bhaskar Acharya-I or Bhaskar-I. According to Dr. Kripa Shankar Shukla of Lucknow University (who worked on Bhaskar-I for his Ph.D) Bhaskar-I had also written another book Aryabhattiya which was a commentary on orignal Arya Bhattiya. According to Hyashi (2008), Bhaskar has discussed in his astronomical treatise among other topics, topics such as planetary longitudes, rising and setting of the planets, solar and lunar eclipses and phases of the moon.

Bhaskar-I belonged to the school of Arya Bhatta. He was born in Ashmak which is located between the rivers Narmda and Godavari. Both his monumental works were held in great esteem (particularly in central India) right up to 15th century A.D. In both these works the count of time is from the start of Kalayuga.

Kalyan Verma: There is some doubt regarding his time period. Where as according to Sudhakar Dewedi it should be around Shak 500, according to Shankar Balkrishan Dixit it should be around Shak 821. He wrote an astronomical work titled 'Sarawali Jatak' which is bigger than a similar earlier work titled 'Braha-Jatak' by Varahamihira. He mentions in this work that this work is based on Hora Shastra composed by Varahamihira, Yayan and Narendra. It has 42 chapters. Later on Bhatitpal refers to it in his work.

Brahma Gupta: Brahma Gupta was a renowned astronomer and mathematician of his times. Brahma Gupta was born in Shak 518(Vikram 653). He wrote Brahma-sphut Siddhanta in Shak550 (Vik. 685). In this work he mentions at several places that the computations performed using rules mentioned by Aryabhatta, Shrishen, Vishnu Chandra, etc. do not yield correct locations of the planets as per their actual observed locations, and therefore should not be used in their original form without first making necessary suitable corrections. This shows that Brahma Gupta compiled his work 'Brahma-sphut Siddhanta' after carefully computing the correct positions of the planets based on actual observations. He was of the view that in case there is a difference between the observed and theoretically computed position of a planet, then necessary adjustments be made in computational formulae to make the computed positions tally with observed ones. He was perhaps the first one in India to systematically separate in his works, mathematics based topics from astronomy related topics and put these in separate chapters.

In his writings, BhaskarAcharya relied upon the basics of the work of Brahma Gupta. Some of his works were later translated into Arabic as well. These are: 'Al Sindh-hind` and 'Al Arkand'. The first is the Arabic translation of Brahma Gupta's 'Brahma-sphut Siddhanta', and the second the translation of his work titled 'Khandkhadyak'.

Brahmasphut-Siddhanta: This monumental work of Brahma Gupta has 24 chapters in all. Of these while the first eleven chapters are related to astronomy, the twelfth chapter is exclusively devoted to mathematics. Chapters 13 to 18 are in question-answer form. Questions on different aspects of astronomy are first posed and then an effort is made to provide their answers. In chapter 19 it is explained as to how the length of the shadow of a pole can be used to calculate the height of the pole as well as the time. Chapters 20 to 24 are again related to astronomy.

This work shows that Brahma Gupta, besides being an expert in astronomy, was also well versed in mathematics related subjects such as algebra, geometry, and numerical computations, etc. Most of what he wrote more than 1300 years ago still holds and is relevant! According to Hayashi (2008) this work was translated into Arabic in around 771CE and had great impact on Islamic astronomy and mathematics.

Khandakhayaka: Khandakhayaka is another book written by Brahma Gupta in the year Shak 587 when he was 69 years old. It provides methods which are simple and easy to use for determining Tithi, Nakshatra, and several other numerical computations related to the movement of planets. In this work, Brahma Gupta reinforces Arya Bhata's idea of considering the beginning of the next day from midnight. He also calculated the instantaneous motion of planets, gave correct equations for the parallax as well as some new information regarding computation of eclipses. This work introduced Indian concept of mathematics based astronomy to the Arab world. Surprisingly in this work the author adopted the approach of Arya Bhatta whom he had severely criticized in Brahm-sphut Sddhanta. It appears that with the advancing age, he also visualized the importance of the work of Arya Bhatta. In this book he also introduced certain new ideas and concepts and made some alterations and corrections in his earlier works.

The book has 10 chapters. Whereas the first eight chapters relate to astronomical topics such as the methods for the computation of Tithi, Nakshatra, solar and lunar eclipses, star clusters, the times of rising and setting of the sun, the moon and the stars. In chapter 9 Brahma Gupta mentions his new findings and alterations and modifications to be incorporated in some of his earlier results. In the last chapter he dwells upon conjunction (युति) of stars and planets and position coordinates of Yog stars of Nakshatras.

All this shows that Brahma Gupta was a great astronomer of his times. For a longtime to come the succeeding astronomers had been adopting his conventions and results. This resulted in his name being well known not only in India but even in the Arab world and Turkey.

Lalla: Lalla (8^{th} cent. CE) was the author of Sishyadhivridhi Siddhanta (which means a treatise that expands the intellect of the scholar). In this work an effort has been made to correct several assumptions of Arya Bhatta. The book is divided into two parts: Graha Adhyaya (chapters I to XIII) and Gola Adhyay (Chapters XIV to XXII). The first part deals with planetary calculations such as determining the mean and true positions of the planets, problems pertaining to the diurnal motion of the earth, eclipses, rising and setting of the planets and stars, cusps of the moon, planetary and astral conjunctions and complimentary locations of the sun and the moon. The second part dwells upon the graphical representation of planetary motions and spherics. It provides corrections of the flawed principles where possible, else recommends their rejection. Lalla's work shows the influence of Arya Bhatta, Brahma Gupta and Bhaskara-I. Lalla also authored 'Siddhanta Taliaka'.

Opinions regarding the time period of Lalla differ. Sudhakar Diwedi is of the view that it should be Shak 420. However, according to Sen Gutpa, keeping in view some of his recorded observations it should be 250 years later around Shak 670 as there is a mention of the division of 250. Sudhakar Diwedi's view seems to be incorrect from another view point also. Had Lalla been there at such an early period, then being an astronomer of repute of his times, his work should have found reference in works of later period astronomers such as Brahma Gupta. However it does not find any reference there. Shanker Bal Krishna Dixit regards Lalla to be contemporary of Brahma Gupta which also does not appear correct as it does not explain the idea of division by 250. It thus appears that Sen Gupta's estimate regarding the period of Lalla seems more reasonable. We now briefly review some of his important works.

Shishya-dhivridhi Tantar: This is an important work of Lalla. It is written on the basis of Aryabhattiya. It has one thousand shalokas and is entirely devoted to Astronomy. Techniques for making necessary corrections and adjustments in computed results for making them tally with actual observations are also given. It has no chapters on arithmetic, algebra or geometry. Names assigned to various chapters clearly indicate that this work was written after Brahmasphut Siddhanta. In the book an effort has been made to correct the shortcomings of Brahmasphut Siddhanta. Absence of mathematics related topics in the book indicates that by that time the knowledge of mathematics and astronomy had sufficiently expanded and the two subjects had started being considered separate. It is a bit surprising that from amongst the earlier astronomers only the name of Arya Bhatta appears in this work.

Rattan Kosh: Accoring to Shankar Balkrishna Dixit, Rattan Kosh is another work of Lalla. It is a work on observational astronomy in which an effort has been made to clarify matters related to the planets through observations rather than through calculations.

Padhyamnabha: Col. Brook ascribes shak 700 to be the year of Padhyamnabha. He is considered to be author of a book on astronomy titled 'Yuvharpradeep' as well as a book on algebra which is not now traceable. However, it is not very certain that the same Padhyamnabha is the author of both these books.

Shridhar: Shridhar specialized both in algebra as well as astronomy. He has written a book titled 'Trishitika'. Two copies of it are still available. According to Shankar Dewedi, he is also the author of 'Nayay Kunadali' which was compiled in Shak 913. This is regarded as the period of Shridhar. In the book 'Ganit Sanghrahya' by Mahavir, there is mention of a few sentences from the book Mishri Kavyahar by Mahavir which shows that Shridhar preceded Mahavir who has been ascribed period around 775 Shak by Dixit and 772 Shak by Datt and Singh.

Arya Bhatt-II: Arya Bhatt-II was an eminent mathematician and astronomer of his times which according to Dr. Datt and Singh who around 950 A.D. The wrote a mounemental work on astronomy titled Maha-Siddhanta.

Maha Siddhanta: This is a monumental work on astronomy. This book has 18 chapters in all. These are in the form of 625 shalokas. Out of the 18 chapters, titles of thirteen chapters are same as in Surya Siddhanta and Brahma Siddhanta. The title of second chapter is `Prashnatro Adhyay` and the title of 14th chapter is Gola Adhyay. In this adhyay eleven shalokas are about problems of arithmetic. In the next three shalokas there are questions related to arithmetic, and in the next three shalokas questions on geography. Remaining forty three shalokas pertain to Ahargan and average angular velocities of the planets. Fifteenth chapter has 120 shalokas. These are about arithmetic, and geometry (areas and volumes). Chapter 16 is titled Prashno-Uttar Adhyay. (Question-Answer Chapter) and has problems related to average velocities of the planets in question answer form. The last chapter (eighteenth) is titled 'Kuttak Adhyay'. In this chapter greater stress is laid on 'Kuttak' related problems in comparison to the stress laid on such problems in Brahma-Sphuta Siddhanta. This shows that the period of Aryabhatta-II was later than that of Brahma Gupta.

Munjal or Manjul: According to Col. Brook, the period of Munjal is around Shak 524. However it should be around 854 shak because in the book titled 'Laghumana', Munjal takes reference year of the positions of heavenly bodies to be Shak 854.

Munjal was a great astronomer. Credit goes to him for coming up with new facts about heavenly bodies hitherto unknown. According to Munjal in a Kalap there are 199669 revolutions of vernal equinox. This results in annual recession of verinal equinox by about one `kala` per year which is almost correct even according to modern day calculations. According to Al Buroni it is also mentioned in this book that during his times Ayansh (अयांष) was around 6 degrees and 50 minutes. This yields a time period of Shak 854 (corresponding to 932 AD). Prior to Munjal no earlier work on Indian astronomy refers to recession of equinoxes. Later on Bhaskaracharya-II mentions in his works the value of speed of recession of equinoxes as given by Munjal. Again prior to Munjal no other astronomer had ever mentioned that in the case of the moon, besides 'Mandphal Sanskar' anyother Sanskar also needs to be done.

Another of his book is titled 'Laghumanas'. It has 8 chapters. According to Al Bouroni this is a shorter version of the book by the name 'Vraha Manas' which was written by 'Manu'. Uttpal has writen a commentary on it. So it must have been written around Shak 800.

Uttpal: Full name of Uttpal was Bhatoutppal. He is known for his astronomy related works. He wrote a commentary on Braha Jatak in which he mentions that this commentary was written on Sunday 5th of the waxing moon of Chetra month of Shak 888 (corresponding to 966 A.D.). He also wrote a commentary on Braha Sanhita. In this he mentions that it was written in Shak 888 in the month of Phalgun on Wednesday, the second day of waning moon. Commentary on Khand Khadayak was written earlier as it finds mention in Braha Sanhita. He has also written commentary on 'Laghu-Ghatak'.

His commentary on Braha Sanhita shows that he had thoroughly studied earlier available works on astronomy. He has made use of all those earlier works while writing his commentaries. These works were also earlier utilized by Varahamihira in compiling his 'Vraha Sanhita'. This confirms that prior to Varahamihira, eight to ten works of significance existed. The points which Uttpal highlighted in his commentary on Surya Siddhanta had not been highlighted earlier. He also wrote a commentary on Shatpancha-shikha written by the son of Vrahamihira. This work is in the domain of astrology. In this commentary he has discussed as to what is auspicious and what is inauspicious.

Prithudak Swami: According to Dixit, Prithudak was a contemporary of Uttpal. He wrote a commentary on 'Brahama-Sphut-Siddhanta'. Later Bhaskaracharya-II refers to it at several places in his works. Babu Mishra edited Khand Khadak. A commentry by Aamraj mentions that in Shak 800 Prithudak Swami mentions the value of Ayaansh to be around 6.5 ansh. This puts him earlier than even Munjal! According to Sen Gupta he also wrote a commentary on Khand-Khadyak.

Shripati: Shripati (1045 CE) was an eminent astronomer of his times. He was well versed in all the three branches of astronomy (observational, computational and phalit (astrology)). He had written Siddhant Shekhar (Crest of Established Doctrines), Dhikoti Karan and Rattan Mala (about auspicious periods) as well as Jatak Granth.

Siddhant Shekhar has 20 chapters in which several concepts have been introduced. An illustrative example in Dikoti Karana mentions shak 961 from which it is inferred that Shripati`s period must have been around shak 961 (1031 A.D). According to Probodh Chandra Sen Gupta, a special feature of the theoretical aspects of his astronomy is the mention of a component in the equation of time which arises on account of the obliquity of sun's path. No earlier indian astronomer was aware of this component in the equation of time.

Bhoj Raj: Raja Bhoj is regarded as the author of Karan Granth which was prepared on the basis of Brahma Siddhanta by giving (बीज संसकार) to planets. Its starting point is Shak 964. The positions of planets at that time have been mentioned. Even though Raja Bhoj is regarded as the author of this book, it cannot be said with certainty that Raja Bhoj himself was indeed its author. It could have been written by an eminent astronomer in the court of Raja Bhoj. In fact this book was held in high esteem in central India for four to five hundred years. It has in all 69 shalokas. These are about Madhyamidhikar and Spastadhikar. Rules for determining ayansh are also mentioned.

Shatanand: In shak 1021 Shatanand wrote Bhasvtikaran on the lines of Surya Siddhanta of Varahamihira. This work became quite famous. Malik Muhammad also mentions it in his book Padhavat. It has many special features. Many commentaries were later written on it. It has eight chapters in all. Base year has been taken to be shak 450.

During this period many other astronomers also came on the horizon. However without mentioning them we come straight to Bhaskar-acharya-II whose fame lasted for over 700 years. His monumental works Siddhanta Shiromani and Leelavati are still used as texts for teaching Indian Astronomy to the students of Jyotish. Since there had been earlier another eminent astronomer by the same name who has been referred to as Bhaskar Acharya-I, this one will be called Bhaskar Acharya-II. We discuss his works in the next chapter.

11

SIDDHANT SHIROMANI OF BHASKAR ACHARYA-II

1. Introduction

Bhaskar Acharya himself has mentioned his date and place of birth. His place of birth is Vijadivid Gram near Sahadriya hill and his date of birth is Shak 1036 (1114 A.D). He also mentions that he wrote his monumental work `Siddhant Shiromani` at the age of thirty six and started writing Karan Kutuhal in Shak 1105(1183 A.D). Four of his works gained importance. These are: Siddhant Shiromani, Leelavati, Beej Ganita and Karan Kutuhal. He also wrote a commentary on his own Siddhant Shiromani which is often regarded as part of Siddhant Shiromani itself. In fact Leelavati and Beej Ganita are also sometimes considered as parts of Siddhant Shiromani since Siddhant Shiromani cannot be appreciated without the knowledge of these two works. We now discuss his works in brief.

2. Leelavati

In the beginning of this book some interesting and tricky questions on algebra have been addressed to a girl named Leelavati and their answers provided in an easy to understand way. The book ends with the chapter titled Ganitpash. This is helpful to astrologers for making their calculations about the current location and movements of planets. Several commentaries have been written on this book.

3. Siddhanta Shiromani

Siddhant Shiromani means jewel of accuracy. It is an important work on astronomy. In this book almost all astronomy related topics have been discussed systematically and in detail. Besides a commentary by Bhaskaracharya himself, several other commentaries have also been written on it.

The book has fifteen chapters. The first chapter is titled Golprashansa. In this chapter after invocation, the basic essentials which an astronomer and an astrologer must know have been given. It has also been mentioned that for deciding the auspicious and inauspicious occasions, it is necessary to know mathematics and positional astronomy. In the last shaloka of this chapter the significance and importance of this work has been highlighted.

Second chapter is titled Golaswarup Prashnadhya. There are just 10 shalokas in this chapter. In each shaloka, the reader first puts a question to the author which is then answered. For example how is it that the earth is standing on its own without any support and still does not fall? What is the shape and size of the earth? Or even when ecliptic (the path of sun in the sky) is divided into twelve equal parts, why does not each part of it appear above horizon for equal intervals of time etc?

In the third chapter which is titled 'Bhavan Kosh', nature of the universe is discussed. It is mentioned that earth is surrounded by the orbits of moon, mercury, venus, sun, mars, jupiter etc. There is no support to earth and it is standing on its own. Asurs, humans, devtas and detiyas live on its surface. The earth is covered with hills, forest, gardens, villages and places of worship etc. and when seen from outside it looks like a cabbage.

He strongly contradicts those who consider the earth to be standing on some support. According to him if it is accepted that there is some support for the earth, then it will have to be accepted that there is some support for that support also and this can continue indefinitely. If in the end it is to be accepted that that is self supported, then why not assume it at the first instance itself. He also strongly criticizes Buddhist's belief that this earth is falling and Jain's view that there are two suns and two moons which appear alternatively. He was also critical of the belief by some that the earth is flat and at night the sun hides behind a hill named 'Meru'. He explains that just as a very small part of the circumference of a circle appears almost a straight line, in the same way earth being a very big sphere, appears flat to a person standing on its surface as he sees only a very small part of this sphere.

A technique is next given for computing the circumference of the earth. For this it has been mentioned that since the latitude of Ujjain is 22 and a half degree north, multiplying the distance of Ujjain from the equator with 16 will yield the circumference of the earth. Some geography related facts have also been discussed in this chapter. In shaloka 48, it is stated as to how the sky will appear to a person on the equator. Both the poles (north and south) will appear to him to be on the horizon in exactly opposite directions. He will also observe the sky to be rotating on his head from east to west. Coordinates of the poles have been also given.

Next the relation between the diameter and circumference of a circle are discussed. Ratio of the circumference to the length of the diameter of the circle is given as 3.1416 (an estimate of the value of π which is quite accurate). He further mentions that the value of the surface area of the earth as given earlier by Lallal is inaccurate (and that is true!). Lallal had computed it by multiplying the circumference with radius (i.e. $2\pi r*r=2\pi r^2$) which is not correct. On the contrary, Bhaskaracharya obtained it by multiplying the circumference with diameter (i.e. $2\pi r*2r=4\pi r^2$) which is correct.

Fourth chapter of Siddhanta Shiromani is titled Madhyagati Vasna. In this chapter, average velocities of the sun, the moon and the planets are given. In the first three shalokas of this chapter it is mentioned that the earth is surrounded by seven layers of space. Clouds move in the first layer. Above clouds there are layers of air in which sun, moon and planets such as mars move. It may be of interest to observe that much earlier to the time period of Bhaskar Acharya-II, Arya Bhatt had stated that just as to a person rowing in a boat in a river, trees on its bank appear to be moving in a direction opposite to that in which the boat is moving, in the same way heavenly bodies appear to us to be moving from east to west because our earth is rotating from west to east. This hypothesis of Arya Bhatt was unfortunately not accepted by the succeeding astronomers such as Lallal , Shripati etc. (including Bhaskar acharya-II).

Next an effort has been made to explain as to why the sun, the moon and the planets move with different velocities even though they move in the same layer of air. The reason given for this is that each of these also has its own intrinsic velocity which is different for each one of them. Comparison is made with a potter wheel on which one can move in the forward direction with different velocities. In the remaining shalokas (8to25) certain definitions and lengths of solar and lunar months, extra lunar month (adhikamas) and when to include it, are given. It has been mentioned that the length of a solar year is 365 days, 15 gharis, 30 pal and 22/30 vipal. Number of years in a Yuga is also mentioned.

Title of the fifth chapter is Jyotipatti. In this chapter certain formulae of trigonometry are given. It has just six shalokas. Next chapter is titled 'Chedagadhikar'. In this chapter rules for locating the sun, the moon and the planets from a given place at a given time are mentioned. In this chapter two alternate hypothesis regarding the motion of heavenly bodies are proposed. According to one of these, the sun, the moon and the planets are travelling in small circles whose centers are moving on a larger circle. According to the second hypothesis, sun, moon and planets are moving in circle but earth is not at the centre of this circle.

Bhaskar Acharya has given a picture titled 'Chedhyak' in which orbits of the sun etc are depicted. Technique for construction of this chedyak has also been explained in detail. Efforts have also been made to explain as to why the apparent diameter of the moon varies and is not always the same. Justification given is that when an object is farther from the observer it appears smaller and when the same object comes closer it appears larger. Views of some of the earlier astronomers have also been contradicted.

Seventh chapter is titled 'Goladhikar'. In this chapter it is explained as to how by cutting a circle in the middle and fixing a sphere on a rod passing through its centre, orbits of planets such as mercury can be depicted .It is also explained as to how a circle such as Yamayotar Khitang can be helpful in the study of astronomy. Clearly these astronomical instruments were meant for training pupils and not for actual observational measurements. Rules for determining Ayan ansh, Kranti, Shar etc, which are helpful in astronomical measurements, are also given in this chapter.

The title of the next chapter is 'Triprashan Vasna'. In this chapter method for determining the time of rising of the sun at a given place as well as the duration of daytime is given. It is also explained as to why the days and nights are always of equal duration on the equator throughout the year. Variation in duration of daytime at a place in latitude 66° is also discussed. Reasons for their being sunshine for several days at a stretch and no sunshine for several days at a stretch during an year at places near the poles are also given. It is also explained as to how sky will appear to an observer at the north and south poles.

Days and nights for those living on the surface of the moon are also discussed. It is stated that departed human souls reside on the surface of the moon. For them moon is under their feet. Sun is above their heads on the new moon day. When moon has moved 6 rashis along its celestial path and it is full moon on earth, then the sun is below the moon and it is Ardratri Amavasia (dark night) for inhabitants of the moon.

The reason why all the twelve rashis do not last for equal intervals of time has been attributed to the inclination (obliquity) of the solar orbit to the equator. It is stated that the part of the solar orbit which is inclined is travelled faster compared to the part of the ecliptic which is not inclined. Next the names of Rashis which are in the inclined part and those which are not in the inclined part are given. Names of the countries where Karak and Mithun Rashis are always visible and never go below the horizon are also mentioned. Effort has also been made to explain certain other similar phenomena. A statement made earlier in this regard by Lallal Acharya has been contradicted.

Following method has been suggested for determining 'Akshansh'. The longitude and latitude that one obtains using a pole are the Akshansh and Lambhansh of that place. The azimulh and altitude of the sun on an equinox are also the Akshansh and Lambhansh of the place.

Several other methods for computing values of useful parameters of astronomy have also been given. It has been stated that the Guru (teacher) may explain the working of these basic formulae to the students using suitable examples.

The next two chapters deal with computations for predicting the occurrence and duration of the eclipses of the sun and the moon. In the next chapter it is explained as to how to determine the position of the point in the sky where the arc of the crescent moon will appear on a new moon day. The subject matter of this chapter is highly mathematical and complex. In the first shaloka it is explained as to why solar eclipse is visible at some places but not at others. Just as the clouds cover the sun, in the same way during a solar eclipse, the disc of the moon moving from the west starts covering the disc of the sun. That is why a solar eclipse starts from the western side and ends on the eastern side of the sun. Since the sun and the moon are at different heights from the earth, the shadow of the moving sun is visible at some places on the earth and not from other places. In the case of a lunar eclipse, the sun covering moon`s disc (in reality it is earth`s shadow that falls on the moon) being bigger in size than the moon, during the eclipse of the moon, both the tips of the moon appear dimmer, and the duration of the eclipse is longer. However in the case of a solar eclipse the covering object (moon) being smaller in size than the sun, the edges of the eclipsed part are sharper and the duration of solar eclipse generally shorter. Methods for drawing necessary diagrams have also been given. In the chapter titled 'Shrangonit Vasana' justification for waxing and waning of the moon is given.

Astronomical Instruments: The next chapter titled 'Yantra Adhyay' is devoted to methods for the construction of astronomy related instruments. `Yantra` means an instrument. It has been emphasized that without appropriate observational instruments, it is not possible to gather accurate information about the location and the movements of various heavenly bodies. Instruments which have been described are: Shanku, Ghati, Chakra, Chap, Turya, Phalak and Dhi. Out of these Dhi is considered to be the best. An other instrument is Gol. This is same as Goladhikar discussed earlier.

Regarding Nadhi Yantra, it is stated that to construct it make a circular rim of wood and mark Ghati etc on its rim. Now fix a rod perpendicular to the plain of the wheel. Passage of time can be measured by observing the movement of the shadow of the rod on the rim. This yantra can be fixed in a horizontal or a vertical (विपुवत) plane.

Yashti means a stick or a pole. Name itself suggests the type of instrument it must have been. No specific method has been suggested for its construction. There is also very little discussion about Shanku. Only thing that has been mentioned about it is that it should be constructed with material taken from the tusk of an elephant!

Ghati Yantra has the shape of a hemisphere having a hole at its bottom and is to be constructed with copper. It is to be put in a tub containing water. Water gradually starts entering this pot from the hole at its bottom. As a result the pot starts sinking in the tub. Gradual sinking of the pot in the tub of water is used as a measure of the passage of time.

Another instrument discussed is Chakkar Yantra. It is recommended that this instrument be made either with wood or metal. It is in the form of a circle whose rim is marked into 360 parts at equal intervals. It is suspended with a chain and used as a sun dial to record the passage of time. It can also be used to measure the altitude of the sun. Half of a circle (semicircle) is called Chap Yantra and further half of chap Yantra (a quadrant of a circle) is called Turya Yantra. However these have not been discussed in any detail.

Next yantra which has been discussed in greater detail is a Phalan Yantra. It is rectangular in shape with dimensions '9o ungals' broad and '180 ungals' long. This rectangular plate is to be suspended by a chain tied to the middle of the longer side so that it can rotate about it such that the chain always remains in a vertical position. Lines are to be marked on it as per instructions and a nail is fixed in it. About this nail, another plate measuring 60 ungals in length one ungal in breadth and half ungal in thickness can rotate in such a manner that one of its edge is always on the central vertical line of the bigger rectangle.

Technique for its use has also been explained. The instrument is to be put in the open so that the rays of the sun can fall on its both sides. The altitude of the sun can be known from the shadow of the nail. By adjusting the direction of the plate towards a star or a planet its altitude can also be determined. (This instrument seems to be the predecessor of 'Astarlab' instrument of Arabs.)

Some western critics are of the view that Bhaskar Acharya-II did not consider astronomical instruments very essential for the study of astronomy. That was perhaps why he laid more emphasis on computational rather than observational aspects of astronomy. This view is formed on the basis of one of the shalokas of Bhaskar Achrya which states that for the study of astronomy an intelligent person does not need voluminous books and sophisticated instruments. With a stick held in hand, and with one eye fixed at one of its ends and the other end pointing towards the heavenly body, one can determine its location. Using this simple technique one can measure all the observable objects on land, water and sky. He named this simple instrument 'Dhi'(which means intelligence).

He also discusses different ways in which it can be used. For instance he mentions: Dear friends, suppose a pole standing vertically on earth at some distance from the observer is behind the building of a house which is fully covering it (except its top). In case one can determine the height and the distance of this pole from the observer, then he will be considered an extremely intelligent person. Later on Bhaskar Acharya himself provides the answer: This can be done by measuring the angles subtended by the top of the pole from two different positions at known distance from each other on the straight line joining them to the base of the pole.

Next an instrument termed 'Automatic Instrument' has been described. According to modern science an object or an instrument can work on its own only when energy is provided to it by use of fuels such as coal, petrol etc. Therefore it is obvious that the so called `Automatic Instrument` as conceived by Bhaskar Acharya must not have seen the light of the day. Technique for its construction as given by Bhaskar Acharya is as follows: construct a circular rim of a wheel using finally chiseled wood. Now fix rods connecting the centre of the wheel to the rim at equal intervals such that each rod is not exactly in the radial direction but slightly inclined to it. All such connecting rods have to be hollow from inside having circular cross sections of equal radius. Now put mercury in each of these hollow rods so that these are half full and seal the openings of the rods. Now fix a rod at the centre of the wheel perpendicular to its plane and suspend it from two vertical poles (like the axle of the wheel of a bicycle). Now if such a wheel is slightly pulled from its rest position it will continue moving on its own. However according to modern science this is not possible. Bhaskar himself has mentioned that such an instrument has no relevance to astronomy and this and earlier Dhi Yantra have been described as mentioned in earlier records.

In chapter 14, seasons of the year have been described in poetry form in fifteen shalokas. This chapter has no direct relevance to astronomy. Bhaskar Acharya himself admits that this chapter is given just for recreation.

Next chapter is titled 'Prashan Adhya'. In this chapter questions related to astronomy have been asked and answered. One such question is: There is a town 90 Aansh to the east of Ujjain and 90 ansh west of Ujjain town is another town. There is still another town which is 90° from this town in ईशान कोण direction, again 90° from the town in the west there is a town in वायु कोण direction. Use this information to determine the latitudes of the places. Bhaskar Acharya himself has provided the answer. These are 0°, 0°, 45° and 30°respectiveiy.

The last chapter is titled 'Jyoti Patti'. In this chapter techniques for determining the sine of an angle and certain other trigonometry related topics have been discussed.

4. Other Works of Bhaskar Acharya- II

In his book titled 'Karan-Kutuhala' (calculations of astronomical wonders) easy working rules for making computations related to the planets have been given. These rules simplify making of 'Panchangs'. Some authors mention that he also wrote 'Mahurat Grantha' and 'Vivaha Pattal' which are mostly related to astrology. However these did not become popular.

Faizi, one of the nine jewels in the court of Akbar, translated Leelavati into Arabic in 1587 A.D. Abdullah Rashdi in 1634 A.D.(during the reign of Empror Shahjahan) translated his work Beej Ganita into Arabic. In 1817 A.D. Col Brook translated both Leelavati and Beej Ganita into English. Mahamopadhy Bapudev Shastri translated Gola Adhya into English. Later several more translations appeared which show the significance of Bhaskar Acharya's works. However most of his work is related to theoretical astronomy. For observational data he relied upon 'Bahyasphuti Siddhanta'.

12

BHASKAR ACHARYA-II TO JAI SINGH

1. Introduction

After Bhaskar Acharya-II several astronomers appeared on the firmament of Indian Astronomy from time to time. However none of them could achieve the fame of Bhaskar Acharya-II. These astronomers were usually satisfied with writing either commentaries on earlier astronomer's works of fame or used some earlier work of fame as the base to write astrology related topics in form of Karan Granths. In fact a time came in the history of Indian astronomy when even questioning in any way the correctness of earlier works of fame was regarded as a great sin. Still there were some astronomers of moderate fame in the period from Bhaskar Acharya-II to Jai Singh who need to be mentioned. These are being listed here.

2. Astronomers of Eminence from Bhaskar Acharya-II to Jai Singh

Balal Sen: Balal Sen was son of Shri Lakshman Sen ,the king of Mithila. In Shak1090 (1168 A.D.) he wrote a book on astronomy titled 'Adhbhutt Sagar'. It is a nice work on astronomy on the lines of 'Vrihi Sanhita Granth` of Varahamihira. In this book several earlier works of astronomical significance such as Garg, Vridh Garg, Prashar, Kashyap, Varasanhita, Vishnu, Dharmavtar, Deval, Vasant Raj, Vatkanika, as well as Mahabharta, Valmiki Ramayana, Yavteshwar, Matsya Puran, Bhagvad, Mayurchitra, Rishi Putra, Raj Putra, Panch Siddhantika, Brahma Gupta, Bhatt, Balbhadra, Polish Acharya, Surya Siddhanta, Vishnu Siddhanta and Prabhakar etc have been quoted. Whereas in Varaha Sanhita titles of various chapters end with the 'char' (such as Grahchar, Rahuchar etc) in Adhbhutt Sagar titles of chapters end in 'avrat' such as 'Agustyavrat' which contains information regarding the rising and setting of star named 'Agust'. In this work Balal also mentions several astronomy related events observed in the sky. This shows that Balal, besides being theoretical astronomer, was also observational astronomer who carried out observations of the sky as well. He had observed conjunctions of sun with mercury and venus. He also mentions the positions of the nodes of the ecliptic on celestial equator based on his personal observations. All this shows that as the name itself implies 'Adhbhutt Sagar' is indeed a nice and wonderful work of its times on astronomy.

Keshavarka: This person is different from the father of Ganesh Devagya by the same name. He wrote a book 'Vivah-Vandavan'. According to Ganik-Triangani, his period was around Shak 1164 (1242 A.D.) as according to a commentary of Ganesh Devagya on this work, at the time of writing of Vivah-Vandavan, the Aayan was around 12°.

Kalidas: Kalidas wrote a book titled 'Jyotir Vidabharan'. This book has twenty chapters. It is essentially an astrology related work highlighting auspicious and inauspicious periods. Book is claimed to have been written in Kali Samwat 3068 and there is mention of the court of legendary Raja Vikramadittya. As a result of this, some people regard him to be the Kalidas of 'Shakuntla' fame. However contents of the book show that this work cannot be that old. May be the writer himself (or someone else) has related it to the hoary distant past to provide it an aurora and authority as it primarily deals with prediction of auspicious occasions for performance of important rituals such as marriages. However a critical study of the contents of this book shows that this Kalidas was most likely a contemporary of Keshvarka.

Vavilal Kochnna: Vavilal Kochnna was from Telegana region of south India. In shak 1220 he wrote a Karan Granth in which Phalgun Krishna 30, Guruvar (Thursday) Shak 1219 is mentioned. This book is based on modern Surya Siddhnata. In 1825 an English writer Warren wrote a book on astronomy with the title 'Kal Sankalit'. For writing this book he borrowed a lot of material from Vavilal Kochnna's Karan Granth. According to this book the work of Vavilal Kochnna was being used for preparing Panchangs in the Madras province (now Tamilnadu) of India upto as late as 1825 A.D.

Mahadeva: Mahadeva wrote a book on astronomy in Shak 1238. This book is based on the principles laid down in the works of some well known earlier astronomers such as Pittamah, Aryabhatta, Brahma Gupta, and Bhaskar . In the book the locations of various celestial objects at the time of the writing of the book are first mentioned, and then their annual velocities have been given so that their positions at any given instant in future can be computed. The book has in all 421 shalokas. Based on this book Narsingh Debagya in shak 1480 prepared a table in which value of अयनांष as 13°,45′ and पलभा as 4/30 have been shown.

Mahendra Suri: Mahendra Suri was astronomer royal in the court of king Feroz Shah. In Shak 1292 he constructed an astronomical instrument named 'Yantra Raj' (The king of Instruments). In 1370 CE, his pupil wrote a commentary on it titled 'Yantra Raj'. This is a work in Sanskrit on Astroable. It was published by Mahopadhya Sudhakar in Shak 1804 (1882 A.D.) along with commentaries. He mentions the maximum altitude (परम क्रान्ति) of the sun to be 23°,35′ and the current rate of annual change in position of Gamma,the first point of Aries, (अयांष) to be 54 विकला. Longitudes and latitudes of 32 stars have also been mentioned. The book has five chapters. Shankar Diwedi is of the view that perhaps this book is a translation of some Persian work.

Padhya Nabha: In shak 1320, Padhya Nabha wrote a book titled 'Dhruv Brahm Yantra'. The book has 311 shalokas. In the book there is mention of Dhruv Brahm Yantra and how it may be used at night to determine the time by observing star cluster Dhruv Matasya. A commentary on the book was also written by the author himself. Method for determining time during day time by observing the sun, and how it can then be used to determine `Lagan coordinates' of the representative stars of 28 important Nakshatras is also given. The entries in this book show that these were recorded at a place in latitude 24° North.

Damodar: Damodar wrote a Karan Granth titled 'Bhattulya'. The writing of this book started in Shak 1339 (1427 A.D). He was pupil of Padhya Nabha and had also written a commentary on his book titled 'Dhruv Brahm Yantra'. In this book he mentions the velocity of recession of equinoxes (अयन षति) as 58 vikla per year. He has also given the coordinates (भोगांष और षर) of representative stars of several star clusters (Naxatras). These coordinates are a bit different from those mentioned in other works. This shows that perhaps the author himself had made the recorded observations.

Ganga Dhar: Ganga Dhar wrote in Kali Samwat 4535 (corresponding to Shak Samvat 1356), a tantric text titled 'Chandra Mahavibhavam Tantar'. It is based on Surya Siddhanta. In this book it is explained as to how by assigning velocities to the planets based on lunar months, the positions of planets at a given instant can be determined.

Markand: In shak 1400 (1478 A.D) Markand prepared a table which is named after him. It is based on Surya Siddhanta and can be used to determine the `tithis`. This table is still being used in some parts of north India to prepare Panchangs. In shak 1688, Gokalnath wrote a commentary on this table which was later translated into English. In Shak 1805 (1888 A.D), Pt. Raghuvir Datt published a table which gives Tithis, Naxshatras, Yogas, and daily motions of planets. This table makes computations much simpler for astrologers. It also contains information necessary for preparing Panchangs.

Keshav-II: Keshav-II was born in Nandi Gram situated on the western coast of India. However his date of birth is not mentioned. He is different from Keshav mentioned earlier and who is the author of Vivah-Vrindavan. Keshav-II was a learned scholar and a great critic. He laid great stress on accurate observations and precise computations. He was a trend setter for the generations that followed. His well known work is titled 'Grah Kutik'. He also wrote a commentary on it. He was particularly adept in the studies of planets. Noticing major variations in their actual observed positions and positions obtained using computations based on Aryabhattiya and Surya Siddhanta, he obtained values for corrections which need to be applied to the theoretically computed positions of various planets, sun and moon (particularly in the case of computations which are used in making predictions of eclipses).

Writing of Grah Kutik was started in Shak1418 (1496 A.D). Besides Grah Kutik, he also wrote Varsh Grahsiddhi, Jatak Paditi, Jatak Paditi Nivriti, Tajak Padditi, Siddhant Vasna Path, Mahurat Tatav, Kayasthadi Dharam Padditi and Ganit Deepika. All this shows that Keshav-II was a learned scholar well versed in different branches of astronomy. He wrote about planets the way present day astronomers would normally write.

Ganesh Devagya: Ganesh Devagya was the son of Keshav-II. Like his father he was also well versed in various branches of astronomy. He was also in favor of doing computations based on accurate observations. His main work is Grah Laghav. In this work, computations have been performed without the use of trigonometric functions such as sines and cosines. Writing of Grah Laghav was started in Shak 1442 (1520 A.D). It was regarded as a great work of its times. Later several commentaries were written on it (by Gangadhar in Shak 1508, by Malliry in Shak 1524 and by Vishwanath in around Shak 1534). Sudhakar also wrote a commentary on it which incorporates commentaries written earlier by Malliry and Vishwanath. Grah Laghav is still popular in Maharashtra, Gujrat, Karnataka and erstwhile Gwalior state. It has fourteen chapters namely: Madhamadhikar, Spashtadhikar, Panchtara Adhikar, Triprashan, Chandragrahan, Surya Grahan, Sthuul Grahan, Saddha, Rising and Setting, Shadows of Planets, Shrangounatti, Grahyutti and Mahapat. In their commentaries Vishwanath and Malliry also mention amongst his works Panchang Grahanadikar.

Ganesh Devagya also compiled Viruthichintamani and Laghdu-tithi Chintamani tables that help in determining conveniently the Tithi, Nakshatra etc for preparing Panchangs. Besides the above, Ganesh Devagya also wrote Siddhant Shiromani Teeka, Leelavati Teeka (in Shak 1467), Vivah Vrindavan Teeka (in Shak 1476), Mahurat Tatava Teeka, Shradhadi Nirnay Chandoranav Teeka, Sudhir Janni, Tyni Yantra, Krishna Janamashtmi Nirnay and Holika Nirnay.

Laxmi Dass: Laxmi Dass wrote in shak 1422 (1500 A.D) a detailed commentary (along with supporting illustrative examples) on Shiromani of Bhaskar Acharya. The book is titled Ganita Tatava Chintamanni.

Gyan Raj: Gyan Raj wrote a Karan Granth titled Siddhanta Sundra. It is along the lines of modern Surya Siddhanta. It was written around Shak 1425. The first part of the book is titled Gola Adhya and has 12 chapters such as Shriti Karam, Lok Sanstha etc. Second part is titled Ganita Adhya. It has 8 chapters. Ayansh has not been discussed anywhere in the book. However it has been stated that as mentioned in Surya Siddhanta, it can be determined by finding the actual observed position of the sun and the computed position of the sun at that time as per theoretical computations.

Surya: Surya is the son of Gyan Raj. In his commentary on Beej Ganita of Bhaskar Acharya, he mentions his own name as Surya Prakash Ganita Amrit Koopika. He also wrote a commentary on Leelavatti in Shak 1436 when he was 34 years old. This gives his date of birth to be Shak 1402. Important books written by him are: Leelavatti Teeka, Beej Ganita Teeka, Shripatti Padhati, Ganita, Beej Ganita, Tajak Granth, Kavadya and Bodh Suddhakar Vedanta Granth. Col Brook credits him with the name of the last book although it does not appear in the names of eight of his books which he mentions in his commentary on Leelavatti.

Anant-I: In shak 1447 Anant-I wrote a book titled Anant Suddha which is helpful in preparing Panchangs. According to Suddkar Dewedi this book is essentially a set of tables for easy computations.

Dundi-Raj: Dundi Raj is the author of well known Jatak Bharan Granth. This book is helpful to astrologers for preparing horoscopes and making predictions based on these horoscopes. He is also the author of commentaries on Sudharas of Anant, Greh Laghvodharan, Greh

Phalotpatti, Panchang Phal, Kundal Kalplata. He does not mention his date of birth anywhere. However he was a pupil of Gyan Raj and thus must have been contemporary of Surya.

Nilakanthan Somayagi: In 1500 CE Nilakanthan Somayagi of the Kerla school of astronomy and mathematics wrote a book titled `Tantra Sangraha` in which he revised Aryabhat's model for the planets Mercury and Venus. His equation for the centers of these planets was considered to be the most accurate upto the time of Kepler in 17th century. He also wrote a commentary on Aryabhatta's Arayabhattiya and titled it Aryabhatiya Bhasya. He also authored a treatise titled Jyotir Mimansa which emphasizes the necessity and importance of astronomical observations for obtaining correct parameters needed for computations.

Neelkanth: Neelkanth was an astrologer pundit in the court of king Akbar. He is the author of a well known book titled 'Neelkanthi'. It was written in Shak 5009 (1587 A.D). It is used by astrologers in preparation of horoscopes and for making predictions. This book contains many Persian and Arabic words. Vishwanath later wrote a commentary on it along with illustrative examples. Sudhakar Dewedi also credits Neelkanth with writing of the book titled Jatak Paddati. This book is still popular in Mithla region of northern India.

Ramdevagya: Ramdevagya was younger brother of Neel Kanth. He composed Mahurat Chintamani in Shak 1522. This became quite popular. It is being used as a text at certain places for the training of students in astrology. His nephew (son of Neel Kanth) Govind wrote a commentary on it which also became popular. Ramdevagya also wrote Ram Vinod. It was written in Shak 1512 to please Maharaja Ram Das of Jaipur. It is useful for preparing Panchangs. The book is based on Surya Siddhanta. Beej Sanskar is also given in this book. It has 280 shalokas in all and is divided into eleven chapters.

Krishna Devagya: Krishna Devagya was chief astrologer in the court of Emperor Jahangir. He is the author of Navankur which is a commentary on the Beej Ganita of Bhaskar Acharya. Ranga Nath also credits him with having written a commentary on Shripatti Pashitti and Chadak Naryana. He does not mention his period anywhere in his works. However according to Suddhakar Dewedi he was born around Shak 1487.

Govind Devagya: Govind Devagya was son of Neelkanth and nephew of Ramdevagya. In shak 1525(1643 A.D.) when he was in Kanshi, he wrote a commentary on Muhurat Chintamani. He was born in shak 1471 and excelled in jyotish, grammar, poetry and literature.

Vishnu: Vishnu was born in a well known family of eminent scholars in the village Golgram in Vidarbha. He wrote a Karan Grnath titled Surprakshya in Shak 1530. A commentary on it along with illustrations was written by his brother Vishwanath in Shak 1545. Kamlakar, the author of Siddhanta-Tatva-Vivek, also belonged to this family.

Mallari: Mallari belonged to the family of Vishnu. He wrote a commentary on Grahlaghav. In this he cites examples from actual observations. This shows that he was adept in observational astronomy as well. He was aware of the reasons for discrepancy in actual observational data and their corresponding values obtained theoretically using past observations, and why there was the necessity of using Beej Ganit to make the theoretically computed positions of the heavenly bodies using past records match their actual presently observed positions. He does not mention his time period anywhere in his works. However according to Suddhakar Dewedi it should be around Shak 1493.

Vishwanath: Like Bhattotpal, Vishwanth was also a critical commentator on astronomical works. He was born in Golgram. In his commentary on Tajak Neel Kanthi he mentions that this work was completed in Shak 1551 (1629 A.D). Commentry on Vishnu's Karan Granth was written in Shak 1545. The practical examples that he chose for illustration in his works are of Shak 1534 as well as of Shak1508, 1530, 1532, 1542 and even 1555.He wrote commentaries on Granth Prakashika, Siddhant Shiromani, Surya Siddhanta, Karan Kutuhal, Makrand, Pathsarni of Ganesh Devagya, Anant Sudharas, Ram Vinod Karan, Samantra Prakashika and Neel Kanth. All these were written while he lived in Kashi.

Narsingh: Narsingh also belonged to a well known family of astrologers of Golgram. He got his education and training from his uncles Vishnu and Mallari. In Shak 1533, he wrote a commentary titled \`Surya Bhashya\` on Surya Siddhanta and in Shak 1543 a commentary on Siddhanta Shiromani titled Vasna Vartik. Compared to other commentaries, these two commentaries have some special features. His works show that he had a good command over theoretical aspects of astronomy.

Ranga Nath: Ranga Nath was born in a well to do family in the village Dashigram located on the banks of the river Payoshni. He wrote a commentary on Surya Siddhanta which was published in Shak 1525 (1606 A.D), the day on which his son Munishwar was born. He was a renowned authority on Jyotish. This is evident from the critical comments that appear in his works.

Munishwar: Munishwar was the son of Ranga Nath. He was born in Shak 1525. He wrote a commentary titled 'Leelavatti Vivarit' on Leelavati, as well as a commentary titled Mirich on Ganit Adhay and Gola Adhya of Siddhanta Shiromani. He was a great admirer of Bhaskar Acharya-II. According to Ganik Tirangani, he also wrote Siddhanta Sarvbhom in which he had used the values of basic units (such as the length of an year) from Surya Siddhanta. Vishvaroop was his second name. He was accredited to the court of Shah Jahan. He mentions the date of coronation of Shah Jahan in one of his books.

Divakar: Divakar was born in Shak 1528 in the well known family of astronomers of Golagram. In shak 1547 he wrote a book titled 'Jatak Margpudhyam'. He also wrote a commentary titled 'Prarorh Manorma' on the lines of 'Keshvi Jatak'. He was also the author of another commentary titled 'Makran Vivaran' which had illustrations on Makrand Sarni.

Kamlakar: Kamlakar was born in Shak 1530 (1608 A.D.) in a well known family of astronomers. In Shak 1580, he wrote a siddhanta granth titled 'Siddhanta Tatva Vivek'. This work was based on Surya Siddhanta and included many innovative ideas. He changed the earlier definitions of new moon and full moon. As a consequence of this, middle of a solar eclipse could occur even hours before or after the time of occurrence of new moon. He was critical of several statements of Bhaskar Acharya and Munishwar which were normally considered correct as these were not contradictory to Surya Siddhanata. This shows that by his time astronomy had got so much bogged down with orthodoxy that any progress or improvement in it looked virtually impossible. In Siddhanta Tatava Vivek he introduces certain new terms which were in use in some foreign astronomies. This shows that he was willing to accept foreign knowledge in astronomy. For example he makes use of the word 'Tulansh' in place of term 'Rekhansh' which was earlier in use. (\`Tuul\` is a Persian word meaning length).

Assuming a place on equator named Khaldat as the origin of reference, Kalmakar gave longitudes and latitudes of 20 cities such as Ujjani, Kashi etc. According to the current estimates, Khaldat should be a place on equator 34°,52' to the west (or east) of Greenwhich. However at such a location on equator, there is no land. This location is in ocean.

He has also described at length the use of an observational instrument named 'Turi'. He also mentions that during a solar eclipse an observer on moon will see an eclipse on earth and that is correct. He also gives the causes behind earthquakes, clouds, and lightning (अलकापात) and these are to an extent correct. He also gave some new results and facts in arithmetic, algebra, geometry and trigonometry. He also prepared a table for computing trigonometric functions such as the sines and cosines of angles. These tables were more convenient to use than the earlier tables existing at that time.

He also prepared a table for converting भागांष of a planet into its विपुवांष which was not there earlier in the literature. In spite of all such innovations, he was dead against research. He was in fact contemporary of Munishwar and both were strong critics of each other. Where as Munishwar was a follower of Bhaskar Acharya, Kamalkar was follower of Surya Siddhanta. His Siddhanta Vivek is still studied by students aspiring for degree of Jyotish Acharya.

Nitya Nand: Nitya Nand was a resident of Inderpuri near Kurukshetra in Haryana. In 1639 A.D. he wrote Siddhanta Raj. It has chapters on Gola Adhyay and Ganita Adhyay. A specialty of this work is that it describes a method that determines the current positions of planets using the current value of Sanyasan as base. It is also mentioned there that the use of Sanyasan (and not Niryan) is an appropriate method for determining the current position of a planet. According to him there are 1577847748101 Sanyasan (solar) days in a Kalap. This results in the length of a solar year to be 365 days, 14 Ghari, 33 pal and 7.40448 vipal. According to modern observations the length of a solar year is 365 days, 14 Ghari, 31 pal and 53.42 vipal. This shows that keeping in view the observational facilities that were available at that time, his value was not very far from the currently best known value. He recommended use of Beej Sanskar while specifying positions of planets. He also gave the position coordinates (भागांष और षर) of 84 well known stars.

Ayuta Pisarati : Ayuta Pisarati(1550-1621 CE) wrote Sphuta Nirnaya (location of true positions of planets). It gives in detail method to apply elliptical correction to existing motions. It was later expanded as `Rashi Gola Sphutaniti` (true computations of the sphere of Zodiac). Another of his work `Karanottama` deals with eclipses; complementary relationship between the sun and the moon; and determination of the mean and true positions of planets. In Uparaga Kriyakrama (method of computing eclipses) he suggests improvements in existing methods for calculation of eclipses.

13

JAI SINGH AND HIS OBSERVATORIES

1. Jai Singh

Jai Singh belongs to the ruling family of Jaipur state of Rajasthan. He was born in 1686 A.D. At the young age of just thirteen, he ascended the throne of Amber. At that time Aurangzeb was the Mughal Emperor of India. Jai Singh faced some difficulties in the earlier years of his reign. However soon he gained complete control over his state. Shortly after Jai Singh ascended the throne, the Mughal Emperor Aurangzeb died. He was succeeded by Mohammad Shah. Jai Singh was on the right side of Mohammad Shah. Mohammad Shah appointed him the governor of Agra province in 1719 A.D. and soon after the governor of Malwa as well.

Jai Singh lived in turbulent times. However he was a shrewd politician and adopted strategic policy popularly known as 'Chanakya Niti' and was successful in it most of the times. He founded a new capital for his state and named it Jai Nagar which later came to be known as Jaipur (the capital of modern Indian province of Rajasthan). He got a number of dharamshalas and caravan sarais built in Jaipur. Gradually it became a great centre of learning.

2. Fascination with Astronomy

Jai Singh had a fancy for astronomy since childhood. He himself studied its fundamentals and basic principles. He gathered knowledge of astronomy from different sources, both Indian as well as foreign. He studied 'Almajest' of Tolmey, Astronomic catalogues of Al`Beg, and books about astronomical laboratories as well. He also studied stellar catalogues of Lalhigher, Historica Celestis Britannica of Phlemstied, Euclid's geometry, and books on plane and spherical trigonometry. He also studied techniques for preparing logarithmic tables. He might have also studied some more books whose titles are not now known as his personal library later got destroyed and it now exists no more.

Jai Singh noticed appreciable difference between the actual observed positions of stars and planets and their predicted positions as obtained from theoretical computations based on the earlier star charts. As a result he decided to prepare new and more accurate tables of the current positions of stars. With this objective in view he studied Indian, Arab and European literature on the subject and also got many of foreign works translated. For carrying out this work, he employed several scholars and even sent some of the scholars abroad.

Those days, for over a thousand years, Tolmey's Syntax had been holding sway in Europe. It had also been translated into Arabic and was holding its sway in the Arab world as well. Jai Singh was highly impressed by this book and got it translated by one of his principal astronomers Jagan Nath who named it 'Smrat Siddhanta '. Jagan Nath has mentioned that Jai Singh took keen interest in and was adept in designing new observational instruments as well as for designing new simpler and more efficient rules for astronomical computations. He realised that astronomical instruments such as Nadi Yantra, Gol Yantra, Digansh Yantra, Dakshinadigbhtti, Vrit Shashthashank, Smrat Yantra and Jai Prakash Yantra were essential for an astronomical observatory.

3. Establishing of Observatories

On finding great discrepancies in the actual observed positions of the stars and their predicted positions as per calculations based on earlier stellar catalogues of Al` Beg, Jai Singh apprised Emperor Shah Mohammad of this fact. He also pointed out that since the dates of religious festivals and religious rituals are decided in advance based on these computations, it was necessary that new and more accurate stellar catalogues be got prepared which would then help in eliminating discrepancies between the predicted and actual occurrence of celestial events such as the New Moon day, the Full Moon day, the time and duration of occurrence of an Eclipse etc. Emperor Shah Mohammad gave his consent to this and asked Jai Singh to go ahead with his project.

Having got green signal from the emperor, Jai Singh first got an observatory built in Delhi. This observatory still exists and is popularly known as Jantar-Mantar. Prior to his times, most of the astronomical observatory instruments were made of metals such as copper which with the passage of time got a little deformed leading to errors in observations. More over such metallic instruments could not be made large in size. As a result of this, it was difficult to inscript minute variations in measurements using such instruments. In order to circumvent the limitations being experienced with these metallic instruments, Jai Singh got the astronomical instruments for the observatory in Delhi built in brick and mortar so that these could be built big in size and even minute variations in observations could be recorded. Another advantage with these brick and mortar built instruments was that there was no question of their getting deformed with the passage of time. The observatory was built equipped with all the major observational instruments.

After getting the observatory built in Delhi, Jai Singh got the observations taken and recorded from there. In order to ensure and cross check the correctness of the observational data collected at Delhi observatory, he later got observatories built at Benaras, Jaipur and Mathura as well, and got observations taken from these observatories also so as to cross check the correctness of observations taken from Delhi observatory.

3.1. Delhi Observatory

The observatories built by Jai Singh do not have identical observational instruments. Delhi observatory has one Samrat Yantra, two Jai Prakash Yantras, two Ram Yantras and one Mishra Yantra. With the passage of time through disuse and lack of maintenance, this observatory fell into a deplorable state. However in 1852 the new king of Jaipur got it renovated. In 1920 again the Maharaja of Jaipur got some instruments reconstructed and fresh markings inscribed. However the new markings were inscribed in mortar and lime and with the passage of time these have started vanishing again. Currently it is being preserved more as an ancient monument and not as astronomical observatory because now more powerful and efficient observational instruments have appeared on the scene.

3.2. Jaipur Observatory

Compared to Delhi observatory, Jaipur observatory has been better preserved. Besides the stone built instruments, there are also metal built observational instruments in it. This observatory has a Samrat Yantra, Shashtansh Yantra, Rashi Viley Yantra, Jaiprakash Yantra, Kapal Yantra, Ram Yantra, Digansh Yantra, Nadi Viley Yantra, Dakshinovrat Yantra, two big Raj Yantras and a seventeen and a half feet diameter Uttansh Yantra Chakra made of copper. It has the largest sundial in the world having a 90 feet high projecting arm.

Smrat Yantra is also built on a grand scale here. It is 10 feet high and 147 feet long. Its cylindrical dome has a radius of 41 feet and 10 inches. It is possible to make measurements with it accurate up to one vikla. However in practice it is not possible to achieve this much accuracy as the edge of the falling shadow is normally not that sharp.

3.3 Kashi (Benaras) and Mathura Observatories

Kashi observatory is located on the roof top of Manmandir temple which was built by Mansingh (an earlier king of Amber). It has Smrat Yantra, Nadivilay Yantra, Digansh Yantra and Chakra Yantra. There is also a small Smrat Yantra. The observatory was built around 1737 A.D. and was renovated first in the nineteenth century and later on a more elaborate scale by the king of Jaipur in 1912 A.D.

Not much is known about the observatory built by Jai Singh in Mathura. With the passage of time it seems to have fallen prey to gradual decay and oblivion because of disuse.

3.4 Comparison with the Observatories of Europe of that Period

Several years after the observations started being taken from these observatories, Jai Singh was made aware of the fact that several astronomical observatories existed in Europe as well and were maintaining records of astronomical observations. When this fact came to his knowledge, Jai Singh sent to Europe a team of experts under the leadership of Padri Manuel to bring back recently complied as well as earlier period star catalogues. When this team returned back with the catalogues, a comparison was made between these catalogues and catalogues recently prepared in India with the help of observations made at observatories of Jaipur, Delhi and Benars. The comparison showed for instance a discrepancy of half ansh between the predicted and actual positions of the moon based on catalogues of Europe which was not there when computations were made on the basis of recent catalogues prepared in his observatories in India. This lead Jai Singh to conclude that the observational instruments that existed in Europe at that time were comparable with the ones that he had got built in India.

The astronomical observational instruments which Jai Singh got installed in his observatories were quite accurate for observations as per standard expected of these instruments in those times. These observational instruments were amongst the best in the world at that time. However these are no match to their counterpart present day instruments.

4. A Comment on Jai Singh's work in Astronomy

From scientific view point, the most remarkable feature of Jai Singh's work on astronomy is its anachronism. When he came on the scene, the telescope had been in use in Europe for more than one hundred years. Observatories had been set up at Paris and Greenwich. Telescope was a revolutionary break with the past. It had freed astronomy from the physical limitations of the eye.

In 1728 Jai Singh sponsored a scientific delegation to Portugal. Jai Singh's choice of Portugal was perhaps ill conceived. With its riches from southern America it had gone into Mughal style of pomp and show and had become devoid of any scientific credentials. In fact 18th century belonged to France and England which were engaged in bitter commercial and naval rivalry. Both were great patrons of astronomy because of its utility as a valuable navigational aid.

Jai Singh's India on the other hand had no use for Astronomy. Here astronomy was no more than a pastime. It is also not clear whether Jai Singh was aware of Copernican revolution that had taken place in Europe and the widespread use of telescope. Jai Singh failed to recognise the significance of European developments. He did not want to look beyond Samarkand for inspiration. Jai Singh however had made use of telescope. In his Zih-i-Muhammad Shahi he states, 'telescopes were constructed in my kingdom and using these number of observations were carried out'.

5. Zijs Astrotable and Instumentation

Zijs are astronomical tables. These fall into three categories:

(i) Zij-e-Rashadi (direct tables) based on actual observations.

(ii) Zij-e-Hisabi (calculated tables) obtained by correcting observational data for errors such as precession etc.

(iii) Zij-e-Tashil (simplified tables) which were abridged and simplified versions of previous two types of tables meant for specific purposes such as tables for the positions of moon alone.

Zij period began in the 9th century at Baghdad with translations of Brahamagupta's Sanskrit works into Arabic. Zij astronomy made its debut in India under the patronage of king Ferozshah Tughlak who ruled Delhi from 1351 to 1388. Arabic and Persian Zijs were copied and commented upon. Several books on astronomy were written in this period and astrotables constructed. On his orders an astrotable was placed at the highest minar of his capital Ferizabad (in Delhi).

Mughal Emperor Akbar's historian Abul Fazi (1551-1602) lists 86 Zijs in his book `Ain-e-Akbari`. Abu Mulla Farid Dehalvi writing on the reign of emperor Shahjahan (1627-1659) classified all the Zijs complied till date. Owen Gingerich has pointed out that there were at Lahore four generations of astrotable makers whose instruments design remained virtually constant for a century and a half. This suggests that perhaps these instruments were meant for drawing room decorations rather than actual observations.

Ferozshah had also taken steps to Sanskritise instrumentation astronomy. On his orders Mahendra Suri, head astronomer at his court, prepared in 1370 A.D. Yantra-raja, a monograph on astrotable. This was the first Sanskrit work exclusively devoted to instrumentation. In around 1400 A.D. Padmanabha described astrotable of a design different from Suri's thereby implying that it had been taken from some other source. More importantly he also described instrument Dhruva Bhramana Yantra which measures time using observations of star group polar fish that includes Alpha and Beta Ursae Minoris.Zij Era practically came to an end with Jai Singh. The last known Zij treaty was Zij-i Bhadurkhani dedicated to Bhadur Ghulam Hussain Jaunpuri (1760-1862).

6. Astronomy in the Mughal Era

In the seventeenth century, the Mughal Empire had seen a synthesis of Islamic and Hindu astronomies. Islamic observational instruments were combined with Hindu computational techniques. While there seems to have been a little concern for the planetary theory, Muslim and Hindu astronomers in India continued to make some advances in observational astronomy and produced around one hundred works know as Zij Astronomy.

Hamanu had built a personal observatory in Delhi. In fact he died while rushing down the stairs from his observatory located on a roof top of his fort in Delhi. He was in a hurry to be in time to say his evening prayers after having heard the call for prayers from the Mosque. Jahangir and Shah Jahan also intended to build observatories but could not do so. It was towards the decline of Mughal Empire that Jai Singh II of Amber tried to revive both Hindu and Islamic traditions of astronomy. The instruments that he built in his observatories were influenced by Islamic astronomy while computational techniques that were being employed were derived from Hindu astronomy.

14

AFTER JAI SINGH

With the arrival of British in India, there was greater penetration of western thought and behavior which impacted practically all the spheres of Indian society and astronomy was no exception. Gradually more and more scholars started shifting to European astronomy. However there had been still some astronomers who stuck to their old roots and the traditional Indian astronomy. In this chapter we confine ourselves to some of the eminent astronomers of old Indian school who came on the horizon after Jai Singh.

1. Certain Eminent Astronomers of Indian School after Jai Singh

Mani Ram: Mani Ram was primarily a follower of Surya Siddhanta. However he adopted Grahlaghav approach in his work. Through his own observations, he corrected the coordinates of some of the observed heavenly objects. His astronomical work Grehganita Chintamani mentions Kshey-paksh of the morning of Chaitra month as the first day of the waxing moon of the year Shak 1696 and this is close to the date of Grehlaghav. In his works he used the value of `Ayaansh` as given in Surya Siddhanta. The value of `Dhruvank` used is even better than that given in Grehalaghav. The book has in all 12 chapters based on 120 shalokas.

Narsingh (Nee Bapu Dev Shastri): Bapu Dev was a well known shastri of Benaras (Varansi). He was well versed both in the Indian as well as the Western astronomy. He was born in Shak 1746(1821 A.D.) in the village Tonkey on the bank of river Godavri in the district of Ahmednagar of Maharashtra. He was a pupil of Dhundi Raj of Nagpur from whom he learnt Beej Ganita, Leelavati and Siddhanta Shiromani. Later on he became head of Mathematics in Sanskrit college of Kanshi. He was a member of the Bengal Asiatic Society as well as a member of the senates of Calcutta and Allahabad universities.

He was in favour of introducing necessary corrections in the preparation of Panchangs by using more accurate positions of sun, moon and planets obtained from the current observations. With this objective in view, he wrote a book and started preparing Panchangs using the latest available more accurate data. However his efforts met with stiff resistance from the pundits and astrologers of Kanshi led by Sudhakar Dewedi. As a result, the necessary updates and corrections in the making of Jantaries and Panchangs could not see the light of the day (and have not been implemented till date!). Sudhakar Dewedi did not consider Surya Siddhanta to be of Indian origin. According to him it is based on the work of a Greek philosopher Hippopcerous.

However he was not opposed to the use of Surya Siddhant in the preparation of Panchangs. In fact till date Pandits of Kashi, who prepare Panchangs, have been using a dual policy. For fixing the dates of religious festivals they make use of Surya Siddhanta. However for prediction of eclipses they make use of modern astronomical data available in Almanacs knowing very well that if these predictions are made based on the basis of Surya Siddhanta, then there will be discrepancies of several hours in the predicted times of the occurrence and actual occurrence of eclipses. As a result of which people will come to know that the predictions being made by the pundits on the basis of Panchangs are unreliable and untrustworthy.

Bapu Shastri wrote several books on mathematics and astronomy. With the help of Nicolson, some of these were published both in English as well as Hindi. He also translated Gola Adhyay and Surya Siddhanta into English. Both of these translated works were published in the year 1861-62 A.D. In 1866 A.D., he also published books on Arithmetic and Gola chapters of Siddhanta Shiromani along with his own commentaries. In Shak 1805 (1883 A.D), he published Leelavati. From Shak 1797 to Shak 1812, he also published Panchangs based on the data available in Nautical Almanacs. Bapu Shatri died in Shak 1812.

Neelambar Sharma: Neelambar Sharma was born in Shak 1745 (1823 A.D) near Patna in Bihar. He wrote Golprakash in Sanskrit. It was based on European system of astronomy. After necessary corrections and updation, It was published by Bapu Dev Shastri in Shak 1746.The book has five chapters.

Venayak (Nee Kero Laxman Chattary): Venayak was born in Maharashtra in Shak 1746 (1824 A.D). He was professor of Mathematics, Astronomy and Astrology and held senior positions in several schools and colleges of Maharashtra. In Shak 1772 he compiled a book on Astronomy in Marathi which was based on certain English and French books on astronomy. It was published in Shak 1782. From Shak 1787 he started publishing Panchangs with the help of Apa Sahib Patwardhan. These were well received by public. These were known as Nana Patwardhan Panchangs. He also wrote a book titled Tithichintamani for determining tithis.

Leley: Visagi Raj Leley was born in Nasik in Maharashtra in Shak 1749 (1827 A.D) and died in Shak 1817. He strongly advocated the preparation of Panchangs on solar basis instead of lunar basis. For many years he prepared such Panchangs based on Greh Laghav. Later he started preparing Panchangs using Navik Panchangs as the base. However he did not write any book of his own.

Raghunath: Acharya Chintamani Raghunath was born in Shak 1750 (1828 A.D) in Tamil Nadu. He studied European Astronomy and Mathematics. He was a fellow of the Royal

Asiatic Society. He started working in Madras Astronomical Observatory in 1847 A. D. Based on his observations made in this observatory, he prepared a catalogue of stars. He also discovered two new comets. He wrote Jyotish Chintamani in Tamil. It has three parts. The first part deals with planets, their shapes and their average velocities. In the second part he discusses techniques for determining the true velocities of planets at a given moment. Third part deals with Karan Paditti. It has several formulae related to eclipses. In Shak 1791 he started publishing Duganit Panchang based on Navik Panchang. Its publication was continued by his two sons till Shak 1808. In his computations he used the length of year as given in Surya Siddhanta and obliquity of the ecliptic as 22degrees and 5 seconds.

Godboley: Krishna Shastri Godboley was born in Shak 1753 (1831 A.D.) in Bombay Province of British India. After serving in several schools, he retired as a headmaster and finally settled in Poona. He also worked for sometime in the Astronomical Observatory of Bombay. He died in 1886 A.D. In Shak 1778 he, along with Vaman Krishna Joshi Gardey, translated Greh Laghav into Marathi. This was essentially the translation of the original work of Vishwanath. He also wrote in Marathi a commentary on Greh Laghav. In Shak 1807 he wrote a book on the brief history of Astronomy. He was author of some books on Mathematics as well.

Chandra Shekhar Singh: Chandra Shekhar Singh was born in Shak 1757 (1835 A. D.) in a princely family in the village Kandpura near Cuttak in Orissa province. He was introduced to astronomy and astrology by one of his uncles when he was just ten years old. This led to his observing the night sky. With the passage of time, this created in him a curiosity to observe the planets and other heavenly objects, record their current locations and compare these with their positions mentioned in astronomical records. For this purpose, he himself gathered all the relevant information on the subject available from books at his place. He noticed that the computed current positions of planets using earlier records did not tally with their actual currently observed positions. In fact he was making observations with his own self designed and self fabricated crude instruments. Based on these observations he wrote a book titled Siddhant Darpan. It is a nice book on Jyotish Siddhanta. In Orissa province Panchangs are still generally prepared on its basis. The original manuscript of this book is on Talpatras in Oriya. Later it was published by Yogesh Chandra, professor of Mathematics of Cuttak college, along with his own comments in Shak 1821 (1899 A.D). It still serves as a text book for students of Jyotish in Orissa and Bihar.

Shankar Balkrishna Dixit: Shankar Bal Krishna Dixit was born in Shak 1775 (1853 A.D.) in the village Murrarh of Rattnagiri. He studied up to high school and served in various schools and educational training institutes of Maharashtra. He was a brilliant scholar and published in Marathi some books related to Astronomy. With the help of W.M.Seval, he also wrote a book in English titled 'Indian Calendar'.

However his most outstanding contribution is the book titled 'Bhartiya Jyotish Shastra' which is in Marathi. It was completed in Oct. 1888 (Shak 1810). In the first part of this book, the author presents the astronomy of Vedic period, post Vedic period and as it appears in Smritis and Mahabharta. The second part of the book is devoted to theoretical astronomy. Its first chapter is titled 'Ganita Sakandh' and describes ancient postulates on Astronomy such as Pittamah Siddhanta, Vashishth Siddhanta, Romek Siddhanta and Polish Siddhanta. Next are presented later date Siddhantas namely, Surya Siddhanta, Som Siddhanta, Vashisth Siddhanta and Brahm Siddhanta. This is followed by a brief description of astronomers of eminence and their works starting with Arya Bhatt (Shak 421) and ending with Sudhakar

Dewedi (Shak 1806). Specialty of the works of each of these astronomers has also been pin pointed. It next discusses the impact of Muslim Astronomy (Al Bouroni in particular) on Indian Astronomy. The second part of the book presents the views of various scholars on Bhavana Sansthan. A detailed discussion on obliquity of the ecliptic is given in the third part of the book. The fourth part deals with observational Astronomy. In this part matters related to stellar observations and instruments used for such observations as mentioned in the ancient books of the past are presented.

In Prakaran one (part 1) of Spastadhikar, the positions and velocities of planets as given in different works of the past authors are given and discussed and compared. In Prakaran two, Panchangs and various other calendars are discussed and deliberated upon in detail. In the Prakaran three there is a chapter on Panchang Shodhan Vichar. Here it is explained as to why it is necessary to make corrections in Panchangs and why sun based Panchangas are more natural. Next is a chapter in which there is a brief discussion on Triprashna Adhiakr, eclipses of the Sun and the Moon, transits of stars, and the times of rising and settings of various heavenly objects. This is followed by Shrangonatti, Grehutti, Bhagrahutti and Muhapat chapters. In Bhagrutti chapter there is a discussion on stellar clusters and their representative prime stars. In Sanhita Skandh part, there is a description of books about Jatak Shastra. It is also explained as to how horoscopes are prepared and what do they signify. Book ends with Tajak (Arabic name for astrological predictions). At the end of the book there is a bibliography of related books and their authors.

Ketkar: Venktesh Babuji Ketkar was born in Shak 1775 (1854 A.D) and died in Shak 1852 (1930 A.D). He worked as headmaster in an English medium school. He was well versed in Indian as well as Western astronomy. He wrote several astronomy related books in Sanskrit and Marathi such as Jyoti Ganita, Ketki Greha Ganita, Vijayant and Nakshatra Vigyan.

Tilak: Bal Ganga Dhar Tilak was born in Shak 1778 (1856 A.D). He was an eminent scholar of mathematics, science, astronomy, ancient history, philosophy and Vedas. He also took part in the freedom movement of India as a result of which he had to go to jail also. He was popularly known as 'Lokmanya'. He was editor of Maratha newspaper in English language and Kesri newspaper in Marathi language. Out of his several works, three which are most well known are: 'Orien', 'Arctic Home in the Vedas' and 'Geeta Rahasiya'. Orien is related to astronomy and was written in 1893 A.D. In this book he has tried to establish the period of Vedas based on the actual location of vernal equinox in the cluster Orein in Vedic era as mentioned in ancient literature. According to his calculations, this yields the period of Vedas to be around 4500 B.C. Prior to this, the western scholars regarded the Vedic era to be around 2000 B.C. His view was supported by Prof. Yakobi on the basis of his own independent calculations. Max Muller was highly impressed by the depth and novelty of this work. His second work, Geeta Rahasya, deals with the translation and critical study and analysis of the shalokas of Bhagvad Geeta. In fact it was one of the shalokas in Geeta which prompted him to write the book 'Orien' regarding the time period of Vedas. Besides these books, he had also been publishing a newspaper Kesri through which he propagated the knowledge of Indian Astronomy to the masses and the necessity of making suitable modifications in the prepration of Panchangs. He died in the year 1921 A.D.

Sudhakar Dewedi: Sudhakar Dewedi was born in Shak 1782 (1860 A.D) in the village Khujri near Kanshi. He was professor of mathematics and astronomy in Benaras Sanskrit College. He died in Shak 1844 (1922 A.D). He studied in depth ancient literature on astronomy and based on it wrote several books such as 'Deeragh Vrit Laxman', 'Vichitra

Prashan', `Vastav Chandra', 'Shringonati Sadan' and 'Dhuchracha'. In Dhucharcha the orbits of planets based on European astronomy are described. In Pind Prabhakar and Babhram Rakha Nirpuan the movement of the shadow of a pole is discussed. In Dharabharam the motion of earth is discussed. He also wrote a book on spherical astronomy and a book on Eucledian Geometry in verse. In his book titled 'Ganak Trangani' life sketches of ancient Indian astronomers and their works are given. All these books were written in Sanskrit. He also wrote several commentaries in Sanskrit such as: An Illustrated Commentary on Yantra Raj, Leelavati of Bhaskar Acharya, Beej Ganita and Kahnan Kutuhal of Bhaskar Acharya. He also wrote a commentary on Varahamihira's Panch Siddhanta. This was published with a forward by Doctor Thobo. He also published commentaries on Surya Siddhanta. Brahm Sphut Siddhanta, Arya Bhatt–II, Maha-Siddhanta, Yajush and Jyotish. Grehya Laghavi Supphutika also includes commentaries on these by Mllari and Vishwanath. In spite of being such a learned and well read scholar of astronomy, he was not very enthusiastic about improvements and corrections in the ancient astronomical works and techniques.

Pillai: L.D.Swami Kannu Pillai was born in the second half of nineteenth century and lived up to the middle of twentieth century. Not much is known about the place and time of his birth. He was in a way legend who wrote almost an encyclopedia in English on different aspects of astronomy. The work is titled Indian Chronology. It has 23 parts each part dealing with a different aspect of astronomy and their relationship with Western and Muslim astronomies. Staring with Kalyuga, thumb rules for determining tithis, eclipses, adikamas etc are given for a period of over 2000 years. It is a useful book for the students of Jyotisha.

Chotte Lal: The exact place and time of birth of Chotte Lal is also not known. He lived in the second half of nineteenth century and the first half of twentieth century. He was an engineer by profession. He wrote in English a book on Vedang Jyotish. It was published in 1906-07. The book shows that Chotte Lal had a good grasp and understanding of not only Indian astronomy but also astronomies of Greece, Egypt and Babylon. In the book he has compared different disciplines of astronomy.

Durga Prasad Dewedi: Durga Prasad Dewadi was born in 1920 A.D. in the village Pandit Puri near Ayodhya. For several years he was the head of the Sanskrit School in Jaipur. He wrote in Hindi as well as Sanskrit commentaries on Bhaskar Acharya's Leelavati and Beej Ganita. He also wrote Upptarandu Shekar. This is a commentary on the ancient and modern views about Siddhanta Shiromani. He had also written books on spherical trigonometry, quadrature, critical study of Surya Siddhanta, Adhmas, Panchangs and Jaimani Padhamrit (regarding Jaimani Sutra). He had also written books on philosophy and literature.

Chulette: Dina Nath Shastri Chulette was an exceptional type of astronomer. Besides astronomy he was also well versed in Vedas. He wrote several books of which 'Vedkal Nirney' and`Prabhakr Sidddhanta` are the most important.

In the Vedkal NIrney, Chulette has claimed that Vedic era is not just around 4,500 B.C. as concluded by Tilak in his book Orien on the basis of the location of vernal equinox on Marg Sheersh as mentioned in Geeta, but even much earlier (around 18000 years back). This he concludes on the basis of his contention that at that time Vasant (Spring) season did not set in when the sun was in Marg Sheersh Naxatra but when it was Marg Shersh month. In other words at that time vernal equinox was in Anuradha or Jeshtha Naxatra which was the case around 18000 years back. Similarly he claims in his commentary `Kakracharya` on Katyayan Shrosutra that since at that time vernal equinox was between Chitra and Swati

Naxatras, therefore the period of Kakracharya was around 14 to 15 thousand years back. In his book Prabhakar Siddhanta, techniques for accurate computations of the positions planets are described in a simple and easy to understand manner.

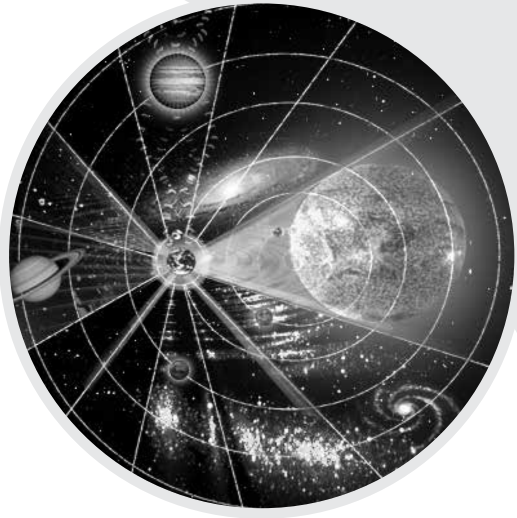
Apptte: Govind Sadda Shiv Apptte was born in 1870 A.D. in Maharashtra. He was professor of mathematics. After retirement he remained in charge of Ujjain Observatory for a long time. He died in the year 1941. In 1921 he wrote a book on astronomy titled `Sarvanand Karan`. It was on the lines of Greh Laghav. Its first part has 11 chapters in which the techniques for computations related to the problems on sun, moon and planets are presented in an easy to understand manner. In another booklet in English he has tried to establish that the starting point of Rashis on the ecliptic is not the point from where the star Chitra is exactly 180° away. It is rather the star Zeta Piescen of Reevti cluster. On this basis, the longitudes of stars and planets come out to be around 4° less. He was supported in this by many scholars of Maharashtra. A method for determining the actual velocity of the moon is also given. This helps in computing more conveniently, the times of occurrence of lunar and solar eclipses. In Surya Karana Adhikar, the times of transit of mercury and mars across the disc of the sun are also mentioned. A table giving the values of sines, cosines and tangents of angles at interval of 10 kalas each is also given. In the Uttra Khand part of the book, a new technique for computing the occurrences of eclipses is also given. Since such type of computations need higher level mathematics, this part has been given the title `Prour Ranjan`. This book was written while he was in Ujjain Observatory. During his stay, he also got the observatory renovated and updated.

Besides the astronomers of eminence listed in this and a preceding chapter, there have also been several other astronomers since Shak 800. They have not been mentioned because of more or less similar and repetitive nature of their works.

2. Astronomy in Kerela

We conclude this chapter with brief reference to astronomy in Kerela. Kerela is the southernmost state of India. It had been in direct contact with the Arab world and the West through sea trade. Therefore it needs a special mention. Initially Aryabhata the first's system was followed by the astronomers in Kerela. In A.D 683, astonomers in Kerala met in Tirunavay to launch the Parahita system of computations. The new method was an amendment of the former method in vogue at that time. The major texts of this system are Grahacarani Bandhana and Mahamargani Bandhana by Haridatta. However over the centuries it was noticed that the observations did not correlate to the computed values as calculated by the Parahita system also. Thus in 1431, Parmesvarah and Drk systems gained ascendance. During this period a number of other literary works based on Parihita and Drk system (known as Karna literature) also appeared. These included Karanratna by Devacharya, Vakyakarna (A.D. 1300), Drkharna by Jyesthadeva (A.D. 1500-1610), Karnasara by Sankara Variyar (A.D 1500-1610), Karnamrta by Citrabhanu (circa 1530) and Sadratnamala by Sankara Varman (1800-38)

Vakyas are the mnemonics used by both the systems to generate different astronomical tables. Aganita Grahacara by Madhava is replete with information on the moon, longitudes of planets and planetary motions stretching over many years. All this is neatly organized in tables. Many works were composed on the topic of the shadow of the moon which help in analysis of problems relating to time as well as planetary motions.



15

INTERACTION WITH THE ASTRONOMIES OF THE WORLD

1. Interaction with Greek Astronomy

The earliest known Indian astronomical work is the Vedanga Jyotisha of Lagadha, which has not been conclusively dated. Post Jyotisha Vedanga, all other Indian astronomical texts are dated with a high degree of certainity to sixth century AD or later. There is substantial similarity between these and pre-Ptolomaic Greek astronomy. Pingree detects the Greek origin of Indian astronomy in these similarities. This has been contested by Van Der Waerden who maintains the originality and independent development of Indian astronomy.

With the arrival of Greek culture in the east, particularly after the invasion of Alexander, Hellenistic astronomy filtered eastwards to India, where it profoundly influenced the local astronomical tradition. Hellenistic astronomy is known to have been practiced near India in the Greco-Bactrian city of Ai-Khanoum from the 3rd century BCE. Various sun-dials, including an equatorial sundial adjusted to the latitude of Ujjain, have been found in archaeological excavations there. Numerous interactions with the Mauryan Empire and the expansion of the Indo-Greeks into India suggest that transmission of Greek astronomical ideas to India occurred during this period. The Greek concepts of a spherical earth surrounded by the spheres of planets, vehemently supported by astronomers like Varahamihira and Brahmagupta, supplanted the long-standing Indian cosmological belief of a flat and circular earth disc.

Several Greco-Roman astrological treatises are also known to have been exported to India during the first few centuries of the present era. The Yavana Jataka was a Sanskrit text of the 3rd century AD on Greek horoscopy and mathematical astronomy. Rudradaman's capital at Ujjain became the Greenwich of Indian astronomers and Arin of the Arabic and Latin astronomical treatises. It was Rudraman and his successors who encouraged the introduction of Greek horoscopy and astronomy into India.

Later in the sixth century, the Romaka Siddhanta ("Doctrine of the Romans"), and the Paulisa Siddhanta ("Doctrine of Paul") were considered as two of the five main astrolonomical treatises, which were compiled by Varahamihira in his Panch Siddhanta (Five Treatises). Varahamhira goes on to state that "The Greeks, indeed are foreigners, but with them this science (astronomy) is in a flourishing state". Another Indian text, Gargi-Samhita, also similarly compliments the Yavanas (Greeks) saying: "The Yavanas though barbarians must be revered as seers for their introduction of astronomy in India".

2. Indian and Chinese Astronomy

Indian astronomy reached China with the expansion of Buddhism during the later Han dynasty (25-220 CE). Further translations of Indian works on astronomy were completed in China during `Three Kingdoms` era (220-265 CE). However, the most detailed incorporation of Indian astronomy in China occurred only during the Tang Dynasty (618-907) when a number of Chinese scholars (such as Yi Xing) became well versed in both Indian and Chinese astronomy. A system of Indian astronomy was recorded in China as Jiuzhi-Li (718 CE). Its author was an Indian by the name of Qutan Xida - a translation of Devanagri word `Gotama Siddha`. He was the director of the Tang dynasty's national astronomical observatory.

3. Interaction with the Arab World

Prof. C.A. Naleno of Rome has written in his book titled 'Encyclopedia of Religions and Ethics' that the Muslims are indebted to India for the fundamentals of computations related to astronomy. A delegation of scholars from India had gone to Baghdad in 771 A.D. One of the scholars in this delegation introduced Arabs to 'Brahmsuphut-Siddhanta' which was written by Brahma Gupta in Sanskrit in 628 A.D. This was known in the Arab world by the title 'Al` Sindhind'. Ibrahim Ibt-Al-Phzari used it to prepare catalogues of stars and planets as per Muslim lunar calendar.

In almost the same period another scholar 'Yakub-Ibn-Tarik' wrote 'Tarkib-Al-Aflak' (Structure of Heavens). It was also based on Braham-Suphat-Siddhanta which was brought by another Indian scholar to Baghdad in 777-78 A.D. (Hijri 161). It appears that almost at the same time Khand Khadiyak written by Brahma Gupta in 665 A.D. was also translated into the Arabic under the title 'Alarkad'. Abul Hasan-Al Ahvazi (who was contemporary of Al Phazari and Yakub-Ibn-Tarik) introduced the Arab world to the movements of planets based on oral information gathered by him from Indian scholars on 'Al Arjbhad' (meaning Arya Bhatt). By the end of the first half of the 5th century of Hijri (11th century A.D.) there were many followers of these books in the Arab world. Some Arab scholars such as Habsh, Anneyriza, Ibn-Asambh wrote books on astronomy in Arabic based on Indian and Greek fundamentals.

Al Bouroni also wrote a book on India in Arabic. This was later translated into English by Prof. Edward C. Sacho of Berlin. In this book, Al Bouroni discusses in some detail the interaction between the Indian and Arab astronomies. Al Bouroni had come to India with

Mohammad Ghaznavi and stayed in India from 1017 A.D. to1031 A.D. During this period he learnt Sanskrit and gathered information about Indian literature, philosophy and astronomy, which he later incorporated in his book. He mentions that the earlier Arab astronomers were also aware of Arya Bhatti and other Indian books on astronomy. An Arabic translation of Arya Bhatti is titled 'Aarjvah' which later got corrupted into 'Aajbhar'. According to him the book in Arabic titled 'Sind-Hind' is in reality the Indian book on astronomy titled 'Siddhant'.

Fragments of certain texts written during this period indicate that Arabs adopted the sine function (that was in use in Indian mathematics) instead of the chords of arc which were in use in Hellenistic mathematics. Another Indian influence was the adoption of an approximate formula for time keeping.

Through Islamic astronomy, Indian astronomy had also influenced European astronomy via translation of Arabic translations of Indian texts into Latin. During the Latin translations of Arabic texts of 12th century, Muhmmad Al-Fazari's `Great Sindhind`, which was based on Surya Siddhanta, and the works of Brahma Gupta, were translated into Latin in 1126 A.D. and these were quite influential at that time.

4. Interaction with West

Europeans became aware of Indian astronomy by the end of 17th century. In this, besides translations of Indian astronomy based Arabic books into European languages, Laplace Belly, Playfare, D'Almbert, Sir William Johns, John Bently etc played a significant role. In the year 1691 A.D. eminent astronomer of France, Jeobni Dominco Cassni, published in Europe literature about Indian astronomy which was brought to Europe by D.La.Lubiur from Assam. Shortly after this, under the auspices of 'Historia Regni Geekorm Bacteriani', Euler published an article about the length of an year as per Hindu calendar being 365 days 6 hours 12 minutes and 30 seconds. In the year 1769 an astronomer named Leventel came to Pondicherry to observe motion of Mars. In the year 1772 he published a table on Trivelore and an article on Hindu Astronomy. An important effect of this was that Silben Belle (the first Mayor of Paris and president of French Assembly who was born in 1736 A.D. and hanged in 1793) was attracted towards it. In 1787 he published a book on Indian Astronomy. This book attracted the attention of Laplace and Playfare. In his lecture to Asiatic Society in 1972, Playfare talked appreciatively on Indian mathematics and Indian astronomy and emphasized the necessity of their systematic study.

Meanwhile in 1789 A.D, A.S.Davis wrote an article on Surya Siddhanta and pointed out that in Surya Siddhanta, the retrograde motion of vernal equinox has been mentioned to be 24 Aansh which is quite accurate and this must have been obtained from direct observations of heavens in around 2050 B.C. Sir William Johns supported it and emphasized that Indian astronomy had its own existence and has not been borrowed or copied from Arab or Greek astronomies. In 1799 John Bently contradicted the statement of Belly that Indian astronomy has a long history and tried to justify that Surya Siddhanta must have been composed around 1091 A.D. Col Brook, D'Almbert and Bently had long discussions about it till 1825 A.D.

However along with this a study was also being made of Indian astronomy. Sir W.Baker, commander of English forces in Bengal, studied the astronomical instruments built in Jai Singh's Benaras Maan- Mandir Observatory. Immediately after that, Playfare presented his own views on it. In 1799 A.D. Hunter described in detail the observational instruments of astronomical observatory of Jaipur. However the true foundations of the knowledge about Indian Astronomy were laid by Weber (1860-68 A.D), Whittney (1858 A.D) and Thebo (1877-1889 A.D). Whereas Weber translated Vedang Jyotish, Whittney translated Surya Siddhanta and Thebo Panch Siddhanta of Varahamihira and presented these along with their own comments. Saacho translated book of Al Bouroni regarding India and tried to establish that during middle ages there was substantial link between Hindu and Greek astronomies. This prompted intellectuals to learn more about Vedic and Post Vedic Era of India. In 1893 A.D. Jacobi and Tilak separately argued to show that Vedic Era in India happened in a very distant past. However Whittney, Oldenberg and Thebo strongly opposed this.

Meanwhile in 1860 A.D., Rev. Brijesh published in American Oriental Society, English translation of Surya Siddhanta and put forward in a scientific way the views of different scholars. Second edition of this translation was published by Calcutta University in 1935.It was edited by Phani Lal Gaungoli and had a forward by Prabodh Chandra Sengupta.

In 1896 A.D., W. Brenand published another book on Indian Astronomy. In the thirteenth chapter of its first part, Greek, Egyptian, Chinese and Arab astronomies are compared with Indian astronomy and their impact on Hindu astronomy discussed. Effort has also been made to establish links of tales such as the marriage of Shiva and Durga, death of Satti, with certain events of astronomical significance. In the second part of the book Surya Siddhanta has been translated into English. This scientist was of the view that the West has not accorded due recognition to Indians for their contributions to literature in mathematics and astronomy. Mr. Brenand had been a Professor in a college in Bengal for several years.

In spite of all these facts, Mr. G.R.K. through his various articles tried to give the impression that Indians do not deserve as much credit for their work on astronomy in the past as is sometimes made out to be. He was successfully contradicted for this by Mr. Neel Bihari Mitra of Prayag in 1915-16 by publishing an article in Modern Review as well as by Dr. Vibhutti Bhushan and Prof. Prabodh Chandra Sen Gupta of Calcutta University by carrying out a systematic comparison of ancient Indian and Greek astronomies.

Some scholars have suggested that it is possible that the knowledge of the Kerela School of astronomy and mathematics may have got transmitted to Europe through the trade route from Kerela by the traders and Jesuit missionaries. Kerela was in continuos contact with China, Arabia and Europe. However there is no direct evidence in the form of specific manuscripts to indicate that such a transmission did take place.

16

MODERN ERA ASTRONOMY

1. Introduction

During the last century, whereas there has been great progress in the field of astronomy in the western world, there has been essentially no progress in the traditional Indian astronomy during this period. It is where it was earlier. Learned pundits of the subject are unwilling to accept any updating in the values of the basic fundamental parameters of observational astronomy computed in the distant past. The learned pundits of Kashi still prepare Panchangs in the traditional way. However in order to avoid being caught by the general public, they make use of modern data available in nautical almanacs to predict eclipses, knowing fully well that if they stick to the original traditional values of desired basic parameters, their predicted times and durations of eclipses will be quite off the mark. It is hoped that perhaps someday orthodox followers of conventional Indian astronomy will take note of the rapid advances which are taking place in this field.

With the introduction of western education system, some of the Indians trained in the western education have now shifted to working in the fields of modern astronomy. Prominent amongst the Indian scientists who have made some outstanding contributions in this direction are: Megnath Saha, S.Chandrasekhar and S. Narlikar. In fact Chandrasekhar, who eventually took U.S.A. citizenship, received a noble prize on his theoretical investigations regarding the structure of white dwarf stars within which the matter is in a degenerate state.

Traditional fields of astronomy such as: how to compute and predict in advance the positions of the sun, the moon and the planets in the sky, prediction of the eclipses of the sun and the moon etc. are now well understood and not much work is being done in these directions. All relevant information regarding these is computed and published yearly in the form of nautical almanacs. Stress in the west has now shifted to trying to understand the inner structure of the planets, the stars and the galaxies, nature of inter stellar matter, structure, and origin and evolution of the universe as a whole. In fact the invention of atom bomb and rapid advances in atomic energy have their origin in the effort of astronomers to understand as to how the sun has been emitting such huge amounts of energy over millions and millions of years without its fuel source getting exhausted.

Astronomy is now divided into several disciplines. Observational astronomy deals with observation of heavenly objects not only in the visible part of the spectrum but also in the X ray and Gamma ray regions and then analysing the obtained observational data through spectroscopes. Space dynamics deals with problems related to the motions of stellar objects, stellar clusters and galaxies. Astrophysics primarily deals with problems of internal structure of stars and their surrounding atmospheres. Spherical (or positional astronomy) deals with the study of positions and relative motions of observed heavenly objects such as the sun, the moon, the planets and the stars. Cosmology deals with origin, structure and evolution of the universe as a whole.

2. Advent of Modern Astronomy in India

It is a significant coincidence that the first British merchant ship reached India the same year as the telescope was invented in Netherlands. Needs of maritime trade acted as a great incentive for the growth of modern astronomy in Europe. Observatories were set up in Paris (1667) and Greenwich (1675) to solve the problems of determining the longitude and latitudes of places at sea. Modern astronomy came to India in tow with the Europeans. Ironically, the earliest recorded use of telescope in India was in the field of pure astronomy and not applied astronomy. Observer was an Englishman Jeremiah Shakerley (1626-1655) who viewed with it the transit of Mercury in 1651. It was done from Surat in western India. In 1689 Jesuit priest father Jean Richaud (1633-1693) discovered from Pondicherry that the bright star Alpha Centauri is a double star.

Things changed after battle of Plassey in 1757 which transformed British trading company into a Jagirdar. In 1764 Major James Renell (1742-1830) was appointed the company surveyor and astronomy was pressed into service for surveying. What however led to the institutionalisation of modern astronomy in India was not the love of stars but the fear of Coromandel coast which is rocky and full of shoals and is devastated by two monsoons each year. It was becoming a grave yard of many a sailing ships. Its survey became a matter of life and death. Accordingly in 1785, a well trained surveyor astronomer Michael Topping (1747-96) was brought to Madras. Next year a small observatory came up at Egmore in Madras. Its founder was William Petrie. Around hundred years later in 1899, astronomical activity of the observatory was shifted to Kodeaikanal and Madras observatory became a purely meteorological observatory which provided reference meridian for the GTS work in India.

3. Physical Astronomy

Meanwhile in Europe a new science of physical astronomy known as Astrophysics was taking shape. It involves the use of photography and spectroscope in the study of the sun and stars. Spectroscopic and photographic techniques were used in India during observations of the solar eclipses of 1868, 1871 and 1872. These attracted many observers from Europe also. However it was the transit of Venus on December 9, 1874 that finally led to the institutionalization of astrophysics in India. The initiative and pressure for it came from European solar physicists who wanted to take benefit of the sunny days of India for their research. The government became interested in the work because it was lead to believe that the study of the sun would help in proper prediction of failure of monsoons which were then (as also now) considered India's lifeline.

With this objective in view, a solar observatory was set up in Dehradun in 1878. It worked till 1925. A solar observatory was also set up at St. Xavier's College in Calcutta in 1879 and at Poona (Takhta Singji Observatory) in 1888 which worked till 1912. The positional astronomy slot had by this time practically fallen vacant. This was filled up by the establishment of Nizamiah observatory in Hyderabad in 1901. Its founder was a rich English educated nobleman Nawab Zafar Jung who started it with a small telescope. After his death in 1907, the observatory was taken over by the Hyderabad government.

C.V.Raman (1888-1970) quit his lucrative job to take up assignment against the newly created post of Palit Professorship of physics at Calcutta University. He installed a 7 inch telescope and worked with it. Later he set up Raman Research Institute at Bangalore. He is famous for his well known `Raman Effect` for which he received noble prize. He took special pleasure in familiarising school kids with skies. On retirement he had a number of small telescopes with him.

Radha Gobinda Chandra born in a Zamindara family in a small village of Bagchar Jessore (now in Bangladesh) had his introduction to astronomy from a Bengali text and practical acquaintance with the sky from the scientific apprenticeship with a lawyer (Kalanath Mukherjee) who was editing a star atlas. He observed comet Helley through binoculars (may be because of the non availability of latest equipments) and later became a regular observer of the variable stars.

While the Indian response to observational astronomy was rather lacklustre, it was path breaking in the realms of theoretical astrophysics. Meghnad Saha (1893-1955), born in a poor family, completed his education through stipends. He was appointed lecturer in Calcutta University, first in mathematics and then in physics. Saha together with his old classmate S.N.Bose (1894-1974) introduced modern physics in the university curriculum at post graduate level, both of them learning it themselves in the process. In 1923 Saha moved to Allahabad University as professor of physics where he set up a school of astrophysics, training students like D.N.Kothari (1906-93). Saha returned to Calcutta in 1938 as Palit Professor.

Another field of theoretical research related to universe around us is relativity. It came into prominence with the publication of theory of relativity by Einstein. However unlike Indian astrophysicists, pioneering Indian relativists were trained abroad. Nikhil Ranjan Sen (1894-1963), a class fellow of Saha and Bose, is perhaps the first Indian to obtain doctorate in relativity. He obtained it from Berlin University. V.V.Narlikar (1908-91) passed mathematics Tripos with distinction in 1930 from Cambridge and went on to obtain Rayleigh prize for his astronomical researches. He came to Benaras in 1932 as head of Mathematics department and remained there for the next 28 years. His son R.V.Narlikar also worked in astrophysics and working with Hoyle in England proposed a cosmological model of universe which is known as Hoyle-Narlikar model. Later he came to India and was asked to head as its director the newly established Inter University Centre for Astronomy and Astrophysics set up at Poona. This post he held till retirement.

By the time the second world war came to an end, it was clear that the British rule in India would be over soon. Plans were therefore afoot to set the scientific agenda for the future. In December 1945 Saha led a five member committee to prepare a plan for astronomical and astrophysical observatories in India. It recommended upgrading of the existing observational facilities and setting up of an astronomical observatory in north India. At the time of independence in 1947, India had only two rather outdated observatories. One on solar physics at Kodeaikanal, and the other non-teaching Nizamiah observatory in Osmania university of Hyderabad. On the recommendations of Saha committee, an observatory was set up at Nanital in north India and a stellar spectroscope observatory at Kavalur in Jawadi hills in Tamil Nadu (it is now named after Venu Bappu). Year 1945 also saw the establishment of Tata Institute of Fundamental Research in Bombay. Its founder was Homi. J.Bhaba (1909-66). An institute of Astrophysics was also set up in Banglore. Later on, an inter university centre for Astronomy and Astrophysics was set up in Poona University. A radio telescope has also been set up near Poona and a solar observatory in Ladhak where visibility is near perfect almost the entire year.

4. Present Scenario

With the launching of interplanetary satellites and positioning of Hubble Telescope in space, there is great impetus to discoveries in astronomy these days. Astronomers all over the world are engaged in this task. India is also participating in it. In the absence of sufficient major world class observational facilities and absence of encouragement, most of the young do not see any bright future in this field. As a result not many promising young people are opting for this field of study. Consequently current Indian research contributions are not at par with those of major advanced countries of the west.

5. Impact of Modern Astronomy on Indian Astronomy

Following the arrival of British East India Company in 18th century, the Hindu and Islamic traditions of astronomy were slowly getting displaced by the European astronomy. There have also been some attempts to harmonise the two. Indian scholar Mir Muhammad Hussain travelled to England in 1774 to study western science. On his return to India in 1774 he wrote a treatise on astronomy in Persian. He wrote about the heliocentric model and argued that there exist not one but infinite number of universes each with its own planets and stars, and this demonstrates the Omnipotence of God. Hussian's idea of universe resembles the modern concept of our universe consisting of billions of galaxies.

6. Impact of Modern Astronomy on Traditional Indian Astronomy

As mentioned earlier, the so called custodians of traditional Hindu astronomy have generally resisted the impact of the modern discoveries and techniques on the conventional Hindu astronomy. The impact of modern astronomy on Indian astronomy is well illustrated by the case study of four Indian astronomers, all born in the nineteenth century. Kero Lakshman Chhatre (1824-84), one time assistant at Coloba Observatory Bombay, sought to update the elements of traditional Hindu almanacs by assigning these their modern more accurate values. Chintamani Ragoonatha Charry (1828-80), his counterpart at Madras and discoverer of variable star (R Reticuli), tried to do the same on the east coast of India. In Bengal there was a general desire to keep pace with new developments taking place in Europe. Radha Gobinda Chandra's (1878-1975) introduction to modern astronomy came not through his European employees, but through Bengali texts. In sharp contrast to these, there was Samanta Chandrasekhar (1835-1904) in Orissa. He was outside European zone of influence and spent his life preparing an astronomical text in Sanskrit on the pattern of Bhaskar-II who had lived seven centuries earlier.

It is hoped that in a not too distant future the scenario will change for the better, and the trustees of traditional Hindu astronomy will accept and incorporate essential updates and modifications in values of essential basic parameters.

17

OUR UNIVERSE

1. Introduction

We live on the planet earth. Most of us are aware of our surroundings only, and like a frog in the well, often imagine the universe to be what we know. In earlier times when the means of communication and travel were limited and hardly a few traveled to far off places, people regarded the universe to be what they knew and were aware of. The earth on which they lived was imagined to be the centre of the universe and the heavenly bodies in the sky such as the sun, the moon and the stars were imagined to be much smaller than our earth. They were supposed to have been created by God to produce natural phenomena such as day and night and seasons. People even imagined earth to be flat. To a large extent all this satisfied their limited curiosity to know about the universe in which they lived.

However, with the passage of time and accumulation of observational data, intellectuals started brooding over the nature of the universe and realized that this type of the model of the universe leaves many observed phenomena unexplained. For instance how is it that sun, moon and stars always rise in the eastern sky, ascend higher and higher in the sky and then start descending towards the west and set in the western sky. There could be two possible reasons for this. The simpler one was to imagine that our earth is stationary and the sky along with these celestial objects is rotating about earth. But then how to explain observed relative motions of heavenly bodies? So the next possibility was that these objects move individually on the surface of sky. However, this model had also its flaws and the best way to properly explain the observed natural phenomena was to accept that our earth itself is a sphere rotating about its axis as well as revolving around the sun. Moreover certain heavenly objects such as moon and planets are also in motion relative to the neighboring stars.

Learning through trials and errors, humanity has now come up with a model of the universe which is vastly different from what was initially imagined to be. We now know that our universe is very big. In fact much bigger than what most of us imagine it to be. Moreover, universe is not earth centric. Our earth is just one of the planets of the sun which is just one of the several million stars that we observe at night in the sky. A brief description of the universe as it is known to us now is briefly given in the following sections of this chapter.

2. Earth and Moon

Contrary to what appears, our earth is not flat but spherical in shape with an average radius of about 6000 km. It is rotating about its axis as well as revolving around the sun. It takes the earth about 24 hours to complete one rotation about an axis that passes through its centre. This is the length of our day. The axis of the earth is along its north south diameter and earth rotates about this axis from west to east. That is why the sun, the moon and the stars appear to move in the sky from east to west just as trees along the roadside appear to move in a direction opposite to that of the motion of the vehicle. Earth also revolves around the sun in an elliptic orbit. It takes the earth about 365 and a quarter days to complete one revolution around the sun. This is the length of our solar year. Very little of the earth's surface is dry. Almost three fourth of its surface is covered with water in the form of seas and oceans. Dry land on which humans can live is around one fourth of its surface.

Sun is not as close to the earth as it seems to be. Its average distance from the earth is about 93 million miles (around 140 million km). In fact the distance is so large that light traveling at the speed of 186000 miles per second takes more than 8 minutes to reach us from the sun. In other words if the sun was to somehow disappear suddenly at this instant we would come to know of it only after eight minutes!

Moon which appears at night seems to be as big as the sun. However, it is not so. It appears big since it is much closer to the earth than the sun. Moreover unlike the sun, the moon does not radiate its own light. It shines by the reflected light of the sun. The part of the moon which faces the sun and is visible from the earth looks bright and its part which is not facing the sun is dark. The cyclic phases of the waxing and waning of the moon show that moon is a satellite of the earth revolving around the earth in a period of about 29 days. This is the length of a lunar month.

Besides revolving around the earth, moon also rotates about its axis. However, the period of its revolution is same as the period of rotation. That is why we always see the same face of the moon. Moreover, the plane of the orbit of motion of moon about the earth is inclined a little to the plane of orbit of the earth around the sun. In case it had not been so we would have witnessed solar eclipse on every new moon day and lunar eclipse on every full moon day.

Moon is our closest neighbor in space. It has been investigated with the help of un-manned and even manned space probes. Unlike the earth, the moon is all solid with no trace of water and air (which are essential for human life) on it. (Recently some traces of water have been detected below the surface of moon). It is much smaller than earth (and that is why it is revolving around the earth). Because of its small size, its gravitational force of pull is also very weak (around one sixth of earth's gravity). A man weighing 60 kilos on earth will hardly weigh 10 kilos on moon's surface. It is because of its weak gravity that it is not able to retain atmosphere around it.

3. Sun and the Solar System

Sun is much bigger than our earth. It is a spherical ball of gas (mostly hydrogen) of radius around 700,000 km. In fact if sun is imagined to be of the size of a football, then our earth is just like a grain of sand. Sun is very hot and is continuously radiating huge amounts of heat and energy. This energy is being generated near its centre through thermonuclear reactions which convert hydrogen into helium and release energy as a byproduct (just as happens in the case of a hydrogen bomb). Its surface temperature is around 6000O K. Temperature keeps on increasing as we move from surface towards its centre where it is around 10^6 ^{O}K (K stands for Kelvin scale of temperature which is similar to centigrade scale but with its zero at – 273°C).

Our earth is a satellite of the sun just as the moon is a satellite of our earth. Our earth along with its satellite moon keeps on moving in an elliptic orbit around the sun. Sun being much bigger and massive than our earth, it is the gravitational pull of the sun on earth moon system which makes this possible. It is revolution of the earth around the sun which gives rise to the naturally observed phenomena of change of seasons and duration of daylight and darkness in a day changing with seasons.

Besides our earth there are eight other prominent planets which also revolve around the sun in orbits of varying distances from the sun. The well known planets of the sun which revolve around it are: mercury, venus, earth, mars, jupiter, saturn, uranus, neptune and pluto, in order of their increasing distances from the sun. Mercury is nearest to the sun. It is a small planet of the size of our moon. Pluto is the farthest. Its behavior is somewhat different from the behavior of other planets. Some astronomers suspect it to have its origin in outer space and its having been captured by the sun when it came close to it during its passage in space.

Orbits of all the planets (except Pluto) are more or less in the same plane. Our earth has planet venus on the inner side and planet mars on the outer side. Except mercury, these planets are quite big in size, some even much bigger than our earth. Jupiter is the biggest planet. Even though these planets are big in size, however, because of their very large distances from the earth they appear as specs of light like other stars in the night sky.

A feature that distinguishes these planets from other night stars is that their light is steady whereas the lights of other stars flicker. Moreover when viewed through a reasonably powerful telescope, they appear small circular discs whereas other stars (being much farther) still appear as dots. Moreover because of their orbital motion around the sun, with passage of time they keep on shifting their positions relative to the neighboring stars.

Venus is the brightest planet. In fact after the moon, it is the second brightest object in the sky at night. On account of its nearness to the sun, it is usually visible either in the western sky in the evening at a place slightly above the point where sun has set, or as a morning star immediately before sunrise in the eastern sky. Its surface is surrounded by whitish gases (most of which are highly poisonous) which give it brilliance. Although surrounded by poisonous gases, surprisingly in mythology, it is regarded the goddess of love.

Mars is reddish in color. In fact when viewed through a telescope its surface resembles the surface of our earth to a great extent. For ages people have been harboring views about the possibility of life existing on mars. Its period of revolution around the sun is almost twice that of the earth. So the length of its year is twice that of the earth. That is why people have sometimes speculated that plants and trees, such as mango tree, which are biennial in yielding their crops and fruits, might have come from the mars. Moon and the mars are two places outside earth where the scientists are exploring the possibility of creating earth like environment so that these can be colonized. However, it is still a distant dream.

Jupiter is the biggest of all the planets. However, it is at such a great distance from the sun that temperatures there are very low. Moreover, it is still not very definite whether it is solid like earth or more or less in a gaseous state like our sun. Saturn is the most charming of all the planets. When looked through a telescope it shows beautiful color rings surrounding it. Being much farther from the sun than even jupiter, temperatures there are still lower. Besides sun and moon the other heavenly bodies with which the ancients were familiar are: mercury, venus, mars, jupiter and saturn. In fact the seven days of the week (namely sunday, monday, etc.) are named in honor of these heavenly objects which were regarded as gods.

It is not only our earth which has a moon, some other bigger planets such as jupiter and saturn have also their moons and their number is more than one. However, nearby planets namely mercury, venus and mars are not known to have any moons.

Between mars and jupiter there is a belt of solid objects of varying masses orbiting around the sun. These are called asteroids. These are regarded to be the remnants of a planet which somehow got broken in the past. The sun along with its planets and their moons and the belt of asteroids is called ‘the solar system’.

Besides the above mentioned objects, the solar system has also several other smaller objects roaming about under the influence of the gravity fields of the sun and the planets. These are called meteors. Some of these meteors when they come near the earth get attracted towards it by the strong pull of earth`s gravity. This increases their speed. These small objects when they enter the atmosphere of the earth get heated up and often burnout leaving a trail of light. These are what are commonly known as shooting stars. Some of the bigger objects which do not get completely burnt before hitting the earth fall on the earth in the form of burning objects. These are commonly known as meteors. Some of the meteors which are reasonably big in size create big craters on the place where they strike the earth. Sometimes they even cause destruction at the place of striking like the impact caused by the striking of a powerful bomb. Records of meteors having struck at different places on earth are available in history. In some cases they leave behind metal ores and even diamonds. Some of the kings of the past used to get their swords built from the metal of these meteors believing that this material being heavenly, the weapons made with it will make them invincible.

Occasionally objects appear in the sky, which look like a star having a tail. These are known as tail stars. A tail star is a star like shining object visible in the sky with a long shining tail. Astronomers call these comets. Comets are in reality small asteroids or meteors with loose matter. The tail is created by the debris surrounding these objects which gets pushed back by the pressure exerted on it by the light of the sun. (Even though it may appear strange, light exerts pressure. In the interiors of stars this pressure is not negligible). Some of the tail stars are visible even during day time. Halley’s comet is one of the most popularly known comets. It appears periodically in a period of around 70 to 80 years. People generally regard the appearance of a comet in the sky, particularly during day time, as an ill omen.

According to commonly held notions of size and distance, our solar system is of very large dimensions. However, as we shall see shortly this is not the entire universe. The known universe is very much bigger than this. In fact our solar system is just like an atom in the material structure of the universe!

4. Stars and Galaxies

Most of the stars which we see at night are in fact as big as our sun and some even much bigger than our sun. They appear as tiny specs of light because of the large distances involved. The star nearest to us is Proxima Centuri which is around four and a half light years away from us (a light year is the distance traveled by light in one year traveling at the speed of 186,000 miles per second). This means that what we see of this star now is the light which started from it more than 4 years earlier. Even though it is the nearest star yet it is not the brightest visible star. The brightest visible star (excluding sun, moon and venus) in the sky is Sirius.

Visible brightness of a star depends both on its intrinsic brightness as well as its distance from the observer (the same object appears dimmer when viewed from a distance). Using standard scientific techniques, astronomers have been able to estimate the intrinsic brightness and distances of a large number of stars which are not only visible to the naked eye but even those which are very far off and are so dim that they become visible only when viewed through powerful telescopes.

Astronomers are now convinced that the most of the stars are intrinsically as bright as our sun and some even brighter than our sun. They appear dim because of the large distances involved. Some of the stars have been estimated to be several million light years away from us. So when we are looking out at stars at night, we are not only looking out far into the space, but are also looking far back in time. In case of a star which is one hundred light years away from us what we are looking at it now is how it looked a hundred years back!

When we look at the sky on a clear pitch dark night, we see amidst stars a whitish hazy cloud like patch stretching across the sky from north to south. People call it `milky way'(Akash Ganga). It is fancied to be the path along which gods (devtas) move in the sky. Initially astronomers regarded it to be some hazy nebulous matter out in space. However, after viewing it through powerful telescopes, astronomers have now realized that this is in fact a cluster of large number of stars. It gets its whitish milky appearance because of the large distance involved. The situation may be compared with the view that one gets of the street lights of a big city viewed from a far off distance while travelling towards that city on a pitch dark night.

Astronomers are now convinced that the milky-way is a cluster of millions and millions of stars which are like our sun. They call it the galaxy. This galaxy, the milky-way, is spiral in shape and has two arms extending out. Our sun is a member of this galaxy and is located in one of its out stretched arms. The stars that we see at night are in fact the nearby stars of this galaxy. It is the central portion of this galaxy, which is very far from us, which appears at night as a milky patch. Another interesting fact that has been observed about this galaxy is that it is not stationary in space. Just as planets in the solar system are revolving around the sun, the sun along with its planet as well as other stars of the galaxy are revolving around the centre of this galaxy.

5. Life history of a star

Our universe has millions and millions of galaxies, each galaxy having millions and millions of stars. Observations show that like human beings most of these stars are similar in nature and structure. Some are young and some old. Like humans, stars also are born, grow, decay and then die. Our sun is a typical star which is still young. Based on observational data and some theoretical studies, astronomers have now formed definite conclusions regarding the inner structure and the life history of a star.

Observations show that what appears to be empty space between stars is not totally empty. This space is filled with what is commonly termed as 'inter-stellar matter' which is primarily hydrogen (in the beginning of the universe, it was pure hydrogen). Due to certain perturbations in the fields of force permeating interstellar matter, a part of this matter gets separated from the surrounding inter-stellar matter and starts contracting upon itself. This is the initiation of the birth process of a star (star in such a state is called a proto-star).

A proto-star is essentially a dark cloud of gas which is not emitting any light. Once such a mass of interstellar matter gets separated from its surroundings, it starts contracting upon itself due to the pull of gravity and gradually takes a spherical shape. As the contraction process continues, pressures and temperatures inside the star start rising. A stage is reached when the temperature and pressure near the centre of the star become so high that a thermonuclear reaction converting hydrogen into helium gets triggered. This thermonuclear reaction is similar to the reaction which is triggered in a hydrogen bomb when it explodes. This thermonuclear reaction generates huge amounts of energy, which the star starts radiating. The star is now virtually a huge shining sphere of gas in which thermonuclear reactions are taking place. As a result of these thermonuclear reactions, the temperature and pressure start rising further in the interior of the star particularly near its centre. This results in still greater amounts of energy being produced and liberated by the star. At this stage the star is said to be a main sequence star and is quite young. Our own sun is currently in this stage.

The huge amount of energy liberated near the centre of the star starts pressing the surrounding matter outwards. As a result the star starts increasing in size and becomes reddish in color. Such stars are known as red giant stars (Our sun is heading towards this stage). With the increase in dimensions of the star, the temperatures and pressures inside start falling. Moreover on account of continuous conversion of hydrogen into helium in the core, the hydrogen content in the core gets depleted. As a result the star is unable to sustain its extended form and the matter in the envelope starts falling inwards towards the core and a contraction phase sets in. Because of this contraction, the temperatures and pressures inside the star start rising still further. A stage is reached when these have risen so high that second generation thermonuclear reactions converting helium in the core into a still heavier element (usually carbon), set in. At this stage two types of thermonuclear reactions take place simultaneously inside the star. One near the centre where helium is getting converted into carbon. The other at the outer edge of the core where hydrogen is still available in the envelope and temperature and pressure are adequate to convert hydrogen into helium. This results in production of still larger amounts of energy. The outward thrust of this energy presses the matter further outwards. As a result the star starts expanding again. Expansion is now more rapid and the star expands to a size much bigger than its red giant stage. Such stars have been observed in the sky and are called 'Super Giants'.

This process of alternate contraction and expansion continues till a stage is reached when the star is unable to maintain its balance and explodes ejecting the matter in its outer parts back into space. This matter contains besides hydrogen traces of heavier elements which were generated inside the star by thermonuclear reactions. It is argued that most of the heavier elements that we have in the universe were generated at one time or the other within the interiors of the stars. Exploding star leaves behind a shining core in the form of a neutron star or even a black hole. Records of exploding stars called Novae and super Novae (when a very big star explodes) are available in history. During the process of contraction and expansion some stars even enter a stage where their light emission does not remain steady and starts varying. These are known as variable stars. Such variable stars are also observed in the sky.

With the death of a star in the form of an explosion as a Novae or Super Novae its life story ends. While the inner core is left in the form of a neutron star or a black hole, the ejected matter merges with the interstellar matter already existing in space for the birth of new generation stars.

As mentioned earlier our sun is a main sequence star gradually tending towards red giant stage. When it enters that state it will start expanding in size. As a result it will start engulfing its nearby planets. A stage is expected to be reached when it will have expanded enough to engulf the earth as well. This will be the end of our earth and life on earth (unless humans find alternate settlements by that time). However, one need not panic on this account for it will be several million years before that stage is reached and none of us will be there to witness it. In fact, life on earth will become extinct even much earlier than that when due to the expanded size of the sun, temperatures on earth will have risen so high that none of the presently known life forms will be able to survive.

6. Neutron stars and black holes

In the normal state of matter nucleus of each atom is surrounded by electrons orbiting around it in different orbits. As a result there is lot of empty space in the atom and its density is comparatively much less. However, when temperatures and pressures increase considerably, (as happens near the cores of stars in later stages of their evolution), the matter there gets compressed so much that the electrons of atoms, which were orbiting around the nuclei of the atoms, start falling into the nuclei. Negatively charged electrons as these fall into the nucleus come into contact with positively charged protons present there, and the two charges neutralize. This is known as degenerate state of matter. In this state most of the matter is not only degenerate but consists only of neutrons (particles with no charge). When such a star sheds its outer shell in the form of a nova or super nova explosion, the left out core is a neutron star. Neutron stars have been observed in universe. Density of matter in such stars is so high that a neutron star of the mass of the sun would hardly be sphere of a kilometer radius. Such stars are usually observed to be spinning very fast around their axes.

In the case of more massive stars, the left out core is even still more compressed. Since the force of gravity is inversely proportional to the square of distance from the centre of attraction and directly proportional to the mass ($g= GM/R^2$), in the case of such stars the force of gravity becomes so large that it does not let any thing (even light) escape from it. Such objects are called black holes. Such objects cannot be seen from outside but their presence is felt on account of the tremendous gravitational pull that they exert on their neighbors. Several black holes are expected to be existing in the universe. In fact it is suspected that most of the galaxies, including our milky way galaxy, have black holes at their centers. It is these black holes which through their strong gravitational pull are not letting millions of stars of that galaxy fly apart.

7. How Big is This Universe

Does our galaxy, which is so big and vast, constitute the entire universe? The answer is a big No. Astronomers observing through powerful telescopes, as well as on the basis of certain other observational and theoretical data, are now convinced that our milky way is just one among millions and millions of such galaxies existing in space. The visible universe is now known to consist of millions and millions of galaxies like our milky way, each galaxy consisting of millions and millions of stars like our sun.

So the universe that we live in is very big. It is not only big but also very very old because the farther we look out into space, farther back we are looking in time. As yet no one has been able to assert with confidence that universe extends only thus far and no farther. Another interesting feature that has been observed by the astronomers is that all the observed galaxies in the universe are receding from us as well as from each other. The more distant an observed galaxy is, faster it is observed to be receding. The situation is similar to the dots marked on the surface of a balloon which is being inflated. This gives rise to the notion of an expanding universe. But expanding into what?

Some persons are septic to the idea of the vastness of the universe. According to them the notion of vastness of universe is created by the fact that we see stars and galaxies all around us in all directions as far as we can see with the help of powerful telescopes. This might be an illusion. They compare it with an idol in a temple placed in a rectangular room having mirrors on walls. When we view this idol we see its image upon image extending in all directions. The situation is also some times compared with a Kaleidoscope. A few colored glass pieces when placed in it give rise to a variety of beautiful intricate changing patterns on rotation.

A question that naturally arises in mind is: How did this universe originate? What is its composition? What is its future and ultimate fate? Such topics have engaged the attention of humanity since distant past and are still not satisfactorily answered. They fall in the domain of a subject which we now call Cosmology. We shall briefly consider it in the next concluding chapter.

18

COSMOLOGY

1. INTRODUCTION

Cosmology is the study of the origin, evolution and the eventual fate of our universe as a whole and the scientific laws that govern these phenomena. Whereas religious cosmology (or mythological cosmology) is a body of beliefs based on the historical, mythological, religious and esoteric literature and traditions of creation and eschatology, physical cosmology is the physical and theoretical study of the same by scientists such as astronomers, astrophysicists, academic philosophers and meta- physists. Although the word 'cosmology' is a recent one (first used in 1730 A.D.), the subject has a long history involving religion, mythology, philosophy and science. We consider here briefly each of these aspects one by one.

2. Religious Cosmology

In addition to observing the sky, the sages of the past had also been curious about the cosmos and the origin of universe and its ultimate fate. Cosmology finds its mention in the scriptures of almost all the religions.

2.1 Hindu Cosmology

Cosmology finds its mention in Vedas where the concept of God and his creation is discussed. Perhaps the most celebrated explanation of the infinite Brahman (the God, the creator of this universe) and his creation (the universe) appears in Vedas at the beginning of Ishopanishad (and elsewhere also). It is: `Purnamadah purnamidam, Purnat purnamudachyate, Purnasya purnamadyaya, Purnamevava Shishyate`. It essentially means that Brahaman (the Supreme Being) is infinite and complete. This physical universe is also infinite. From the infinite Brahaman taking away infinite universe, infinite is still left. Celebrated Hindu ascetic Shankar Acharya has written a detailed commentary on it.

Rig Veda 10.90 and Yajur Veda 31 contain the story of the creation of the universe. Rigveda verses 10.90 (14, 15) and Yajur Veda 31 verse (12, 13) mention the creation of the Sun and the Moon.

12. The moon was generated from his mind. From his eyes the sun had its birth. Yayu and Prana were born from his ear and from his mouth was Agni formed.

13. From his naval came the mid-air. The sky was fashioned from his head, the earth from his feet and from his ears the quarters (cardinal directions). Thus was the world formed.

Rig Veda 10.129. 1-7 speaks more on the creation of universe. Loosely translated it goes like this:

1. Then was not non-existent nor existent. There was no realm of air, no sky beyond it. What covered in and where, and what gave shelter? What water was there, and unfathomed depth of earth?
2. Death was not then, nor was there aught immortal. No sign was there, the day's and night's divider. That one thing, breathless, breathed by its own nature, apart from it was nothing whatsoever.
3. Darkness there was; at first concealed in darkness. This all was indiscriminate chaos. All that existed then was void and formless. By the great power of warmth was born that Unit.
4. There after rose Desire in the beginning. Desire, the primal seed and germ of spirit. Sages who searched with their heart's thought discovered the existent kinship in the non-existent.
5. Transversely was their serving line extended, what was above it then, and what below it?

   There were begetters, there were mighty forces. Free action here and energy up yonder.

6. Who verily knows and who can declare it, whence it was born and whence comes this creation?

   The gods are later than this world's production. Who knows then whence it first came into being?

7. He, the first origin of this creation, whether he formed it all or did not form it, whose eye controls this world in the highest heaven, verily knows it or perhaps even he knows not!

The Rig Veda continues further to describe that

1. Truth and truthfulness were born from intense penance. Hence was darkness born and thence water.
2. From the water ocean was born. The year ordaining days and nights, the controller of every living moment.
3. The Creator then created, in due order, the sun, the moon, the sky, the earth and the regions of air and light.

Rig Veda's view of the cosmos also sees one true divine principle self-projecting as the divine word 'Vaak' (i.e. Birthing). The cosmos that we know was born from the monastic

'Hiranya Garbha' (Golden Womb). Hiranya Garbha is alternatively viewed as Brahma, the creator who was in turn created by God (Brahman) himself.

The universe is considered to be continuously expanding since creation and is expected to disappear into a thin haze after billions of years. An alternative view is that the universe will begin to contract after reaching its maximum expansion limits and ultimately disappear into a fraction of a millimetre dimensions. After billions of years of non-existence, the creation begins afresh and this cycle goes on.

2.2 Puranic View

The puranic view is that the universe is created, destroyed and recreated in an eternally repetitive series of cycles. According to Hindu cosmology, a universe endures for about 4,320,000,000 solar years (this is one day of Brahma). It is then destroyed. After this Brahma rests for a night. This night is just as long as the day. This process named Pralaya (Cataclysm) repeats for 100 Brahma years (i.e. 311 trillion, 40 billion human years). This represents Brahmas life span. Moreover at a given time there are an infinite number of Brahmas performing creation and annihilation of their universes. In Hinduism Brahma is creator but not God, which is Formless, Omnipotent, Omnipresent, and Omniscient. Brahma is creation of God.

We are currently in the 51st year of the present Brahma. 156 trillion years have passed since he was born. After present Brahma's death which is expected to take after around 155 trillion more years, another 100 Brahma years (311 trillion 40 billion human years) will pass before the next Brahma will be born. This process is repeated again and again and forever.

Brahma's day is divided into one thousand cycles (Maha Yugas) during which life, including human race, appears and disappears. A Maha Yuga again has 71 divisions. Each made of 14 Manavantras (1000 human years). So each Mahayuga lasts 4,320,000 years. Manvantra is in fact Manu's cycle, the one which gives birth to and governs the human race.

Each Mahayuga consists of a series of four shorter yugas or ages. Yugas normally move progressively from one yuga to the next. Also each subsequent yuga is of a shorter duraion compared to the one preceding it. The current yuga is Kaliyuga (iron age). It began at midnight of 17th /18th February in 3102 BC.

In Hindu mythology time and space are regarded as maya (illusion). What looks like 100 years in the cosmos of Brahma could be thousands of years in other cosmoses and million of years in some others (the concept of relativity).

2.3 Jain Cosmology

Jain religious cosmology regards this universe (loka) as an ever existing uncreated entity having no beginning or end. Jain texts describe the shape of the universe to be similar to the figure of a human standing with legs apart and arms resting at the waist. According to Jain cosmology, the universe is narrow at the top, broad in the middle and more broad towards the bottom.

Mahapurana of Acharya Jinasena is famous for this quote: 'Some foolish men declare that a creator made this world. The doctrine that the world was created is ill advised and need be rejected. If God created this world, then where was He before its creation? If one says that

He was transcendent then and needed no support, then where is He now? How could have God made this world without any raw material?' If one says that he first made raw material and then the world, one is faced with endless regression.

2.4 Buddhist Cosmology

In Buddhist cosmology, the universe comes into existence depending upon the action (Karma) of its inhabitants. Buddhists posit neither an ultimate beginning nor a final end to the universe. They see the universe as something in flux passing in and out of existence, parallel to an infinite number of other universes behaving the same way.

Buddhist universe consists of a large number of worlds that correspond to different mental states. Like thoughts, beings in these worlds are coming into existence (being born) and then passing out into other states (dying). The universe of these worlds is born and dies because of a universal conflagration that destroys the physical structure of the worlds after an interval. The universes also concurrently coexist.

2.5 Babylonian Cosmology

According to Babylonian cosmology God framed around 3000 B.C., the earth and heavens from infinite 'water of chaos'. The earth is flat and circular and sky a solid dome (the firmament) keeps out the outer ocean (chaos).

2.6 Biblical Cosmology

Bible evolved over many centuries and is the work of many authors. It reflects shifting patterns of religious beliefs. Consequently its concepts of cosmology are also not always consistent.

The universe of ancient Israelites was made up of a flat disc shaped earth floating on water with a heaven above and an underworld below. Humans inhabit earth during lifetime and go to the underworld after death. To begin with the underworld was morally neutral (in other words there was no punishment for misdeeds and rewards for good deeds done in the world). It was in Hellenistic times (after 330 BCE) that the Jews started adopting the Greek idea of underworld being a place of punishment for persons who had done misdeeds and that the righteous ones would enjoy perpetual happiness in heavens above in after life.

Around the time of appearance of Jesus (or a little earlier), the Greek idea that God had actually created the matter replaced the earlier idea that the matter had always existed but in a chaotic state. Most denominations of Christianity and Judaism now believe that a single uncreated God, is responsible for the creation of this universe.

2.7 Islamic Cosmology

According to Islam God created this universe. The highest goal of human life is to regard this life as a prison from which a human must try to escape through good deeds to attain true freedom in the spiritual journey to God.Some citations from the Quran on Cosmology are:

'And the heavens We constructed with strength and indeed We are its expander' (51:47 Sahih International).

'Do not the unbelievers see that the heavens and earth were joined together (as one unit of creation) before We clove them asunder' (21:30 Yousif Ali translation).

'The day we roll up the heavens like a scroll rolled up for books (completed), even as we produced the first creation, so shall We produce a new one: a promise we have under taken truly shall we fulfil it' (21:104 Yousif Ali translation).

3. Mythological Cosmology

Mythological cosmology deals with the world as the totality of space, time and all phenomena. Historically it has quite a broad scope and was in many cases founded in religion. The ancient Greeks did not draw a distinction between this and their model for cosmos. However in modern times it addresses those questions about the universe which are beyond the scope of science. It is distinguished from religious cosmology in that it addresses these questions using philosophical methods. Modern metaphysical cosmology tries to address the questions such as:

What is the origin of this universe? What is its first cause? Is its existence necessary? What is the ultimate reason for its existence? Does it have any purpose? What will be its end? etc.

4. Physical Cosmology

Physical Cosmology is that branch of astrophysics that deals with the study of the origin and evolution of the universe and its ultimate end. Even in the distant past, Greek philosophers such as Aristarchus of Samos, Aristotloe and Ptolemy had proposed different cosmological theories. The geocentric Ptolemaic system was the accepted theory to explain the motion of heavens until Copernicus and subsequently Kepler and Galileo proposed heliocentric system in 16th century.

With the publication of `Principa Mathematica` by Newton in 1687, the problem of motions observed in heavens was finally resolved. Newton`s law of universal gravitation provided physical mechanism for Kepler's Laws. A fundamental difference between Newton's cosmology and those preceding it was the Copernican principle that the bodies on earth obey same physical laws as do all celestial bodies.

Modern scientific cosmology is usually considered to have begun in 1917 with Albert Einstein's publication of his final modification of general relativity in his paper 'Cosmological Consideration of the General Theory of Relativity'. General relativity prompted cosmologists such as Willemde Sitter, Schwarzschild and Eddington to explore the astronomical consequences of this theory. Prior to this (and even for sometime afterwards), scientists believed that universe was static and unchanging (steady state universe).

In parallel to this dynamic approach to cosmology, one long standing debate about the structure of universe was coming to a climax. Mount Wison astronomer Harlow Shapley championed the model of cosmos made up of the milky- way star system only, while Heber D. Curtis argued for the idea that spiral nebulae were star systems like milky-way in their own right leading to the concept of island universe. This difference of ideas came to a climax with the organisation of a great debate at the meeting of U.S.National Academy of Sciences in Washington on April 26, 1920. Resolution of this debate came with the detection of novae in the Andromeda galaxy by Edwin Hubble in 1923 and 1924. Their distances established existence of spiral nebulae well beyond the outermost edge of the milky- way.

Subsequently modelling of the universe explored the possibility that the cosmological constant introduced by Einstein in his 1917 paper may result in an expanding universe depending upon its value. Thus Big Bang model was proposed by Belgian priest Georges Lemaitre in 1927. This was corroborated by Edwin Hubble's discovery of the red-shift in 1929 and later by the discovery of the cosmic microwave background radiations by Arno Penzias and Robert Woodrow Wilson in 1964.By the middle of twentieth century, the following three models of the universe were vying with each other.

(i) Steady State Universe Model: According to this model this universe has always been as it is now and will remain so for ever. It has no beginning or end. Births and deaths of stars and galaxies that we observe are localised phenomena.

(ii) Oscillating Universe Model: According to this model universe expands and contracts periodically about some mean position and the current state is the expanding state of the universe.

(iii) Big-Bang Model (also called Expanding Universe Model): According to this universe started with a Bang from a singularity (a point with infinitely small dimensions) and is expanding. In fact as per present day observational data it has been expanding ever since its birth.

Of these three models, surprisingly the third, namely the Big-Bang model, is currently finding more acceptance. May be that it partly conforms to the beliefs of most of religions according to which there is some external force called God which created this universe. It is further supported by some recent observations made by the COBE and WMAP satellites observing background radiations. These observations match predictions made by a theory called 'Cosmic inflation' which is a modification of Big-Bang Model. In fact in March 2014, astronomers at the Harvard Smithsonian Centre for Astrophysics announced the detection of gravitational waves, providing strong evidence for inflation and Big-Bang. However Big-Bang Model is not very clear about the ultimate fate of the universe. Will it always continue to expand?

5. Concluding Observations

As mentioned in the beginning of this chapter, all these models are in a way conceptual and the flights of human imagination. Whether human mind is really capable of comprehending the universe as a whole, its origin, its creator and its ultimate end is another question. But as they say what is the harm in speculating and imagining. Human race has progressed and evolved by venturing to imagine and speculate into realms unknown. As they say 'keep on'. It is only through trials and errors that humans have learnt and progressed and will continue to do so.

Appendix-I

PANCHANG HOROSCOPE AND ASTROLOGY

1. Panchang

Indian Panchang provides information as to when a particular year starts, what is the date on a specific day etc. Indian Panchang is essentially lunar based. Difficulty in understanding this Panchang arises mainly from the fact that the number of days and lunar months in a solar year are not exact whole numbers. Moreover even the number of days in a lunar month are also not a whole number.

The prime objective in designing Indian Panchang has been to ensure that each new year starts in the same season. For this year has to be a solar year (time taken by the earth to complete one revolution around the sun). For example according to Hijri calendar which is followed by Muslims, an year is exactly of 12 lunar months. (A lunar month is the duration from one new moon to the next new moon or from one full moon to the next full moon). As a result, the length of an year as per Hijri calendar is roughly 29 ½ x 12, i.e 354 days. However the length of a solar year is 365.2422 days. Therefore as per Hijri calendar, if in a particular year, new year begins on spring equinox (when days and night are of equal length), the next year will start around 365 1/4 - 354 i.e. eleven and a quarter days before the next spring equinox. Next year it will start almost twenty two and a half days before spring equinox. This difference will continue to increase from year to year. As a result in case of such a lunar calendar, festivals will not fall in the same season each year. That is why we notice that Id, Muharram and the month of Ramzan fall in different seasons in different years. If in a particular year Ramzan is in winter, then after a few years it will be in rainy season and then in summer and so on. This difference continues increasing till the full cycle is completed after which it will again fall on more or less the same date in winter.

2. Indian Panchang

Literal meaning of the word Panchang is an entity having five components. In fact Indian Panchang contains five sets of information. These are (i) Tithi: which serves the purpose of date, (ii) Var: day of the week (Sunday, Monday etc), (iii) Naxatra: which is the name of the star cluster amongst which the moon is located at that instant, (iv) Yog (sum): This is the sum of the Bhogansh of moon and sun at that moment and (v) Karan: which is half of the tithi at that time.

In addition to the above, Panchangs these days also mention dates as per Gregorian and Hijri Calendars, the length of day (time from sunrise to sunset each day), times of rising and setting of moon as well as of planets and a few selected stars and star clusters each day.

Besides the above factual information, Panchang has also an astrological component based on which learned Pundits claim that predictions can be made regarding the future of an individual.

We now discuss in brief the implications of each of these five components of Panchang.

Tithi and Var (Day of the Week): Tithi is determined by the difference between the positions (measured in Bhangash) of the Sun and moon. During a lunar month, moon completes one circle. Therefore this difference between the positions of these two varies from 0 to 360°. If the difference is between 0° and 12°, it is first tithi. If it is between 12° and 24°, it is second tithi and it continues like this to 3rd, 4th, 5th tithi, till 14th tithi is reached. After that half a revolution is completed and it is either full moon or new moon. After that again tithis are counted from 1 to 15.

From this definition of tithi, it is evident that it can change any time during day or night. That is why the time of start and end of a tithi is also mentioned in the Panchang. The unit of time used in Panchangs is not hour, minutes and seconds but Ghati (which is 1/60 of a day of 24 hours), Pal (which is 1/60 of a Ghati) and Vipul (which is 1/60 part of a pal). For example if against some specific tithi say Panchami (fifth), it is mentioned 4 Ghati, 51 Pal. It means that Panchami tithi ended that day at 4 Ghati, 51 Pal after sunrise.

For civil purposes generally same tithi is considered to last from one sunrise to the next. In view of this in the case of the above example, in which fifth tithi ended about 2 hours after sunrise, fifth tithi will be assumed to last till sunrise of next day even though it ended 2 hours after sunrise.

Unfortunately as per definition, the observed relative angular variations in the positions of the sun and moon from day to day are not identical (since the motions of earth around sun and moon around earth are governed by Kepler's Laws). As a result, some Tithis are of duration less than a day (time from one sunrise to the next) and some longer than a day. It is therefore possible that duration of a particular Tithi may be so small that it started a little after sunrise and ended a little before next sunrise. As a result such a tithi will not appear in the Panchang meant for civil purposes. For example according to Panchang on Wednesday December 13 of the year 1950, 4th tithi ended one Ghati and 5 pal after sunrise and 5th tithi lasted till the next day morning of Thursday upto 5 Ghati and 25 pals before sunrise. As a result it was 4th tithi on Wednesday Dec. 13,1950 and it was 6th Tithi on Thursday Dec. 14,1950, and there was no 5th Tithi in this Paksh (Ardhmass ,half month).

It is also possible that the duration of a Tithi may be longer than the time from one sunrise to the next. Therefore, a tithi can start a little before sunrise on a particular day and last a little after sunrise the next day. As a consequence there will be same Tithi on both these consecutive days. For example, Monday Dec. 19, 1950 and Tuesday Dec. 20, 1950, had same Tithi namely Akadshi(11th). However since the duration of a lunar month is around 29 and a half days, and in this period 30 Tithis occur, therefore in general more tithis are lost than repeated.

From this brief discussion it is clear that the occurrence of a particular Tithi at a place depends on the time of rising of the sun at that place. As a result different places separated apart by longitudes (east west direction) may be having different Tithis on the same date. This can create confusion. To avoid this, usually in a specific region, instead of each place observing its own Tithi, the Tithi of some important central location is observed throughout that region (this is just like the standard time of a country).

Tithis are mentioned in two ways. According to one convention, these start with new moon day and tithis are counted from one to thirty. According to an alternative convention, these are counted from 1to 15 for each half of lunar month called (Paksh). From new moon to full moon called (Shukal Paksh) and from full moon to new moon called (Krishan Paksh).

Var : In the Indian Panchang, the days of the week are seven (as in Gregorian calendar). These are: Sunday, Monday, Tuesday, Wednesday, Thursday, Friday and Saturday. The Sun is regarded as the lord of Sunday, Moon the lord of Monday, Mars the lord of Tuesday, Mercury the lord of Wednesday, Jupiter the lord of Thursday, Venus the lord of Friday and Saturn the lord of Saturday. The names of these lords are same in ancient Indian well as Babylonian astronomy of the west.

Naxatras : When the path of the sun in the sky is divided into 27 equal parts then each part is known as a Naxatra. Moon completes one revolution relative to the background fixed stars in around 27 and 1/23 days.As a result moon (precisely the foot of perpendicular from the moon on the ecliptic) is in each Naxatar for around a day. Indian names of Naxatars are: Ashvani, Bharni, Kritika etc. The starting point of Ashvani is considered to be the first point of Mesh.

When it is said that at this moment Naxatar is Ashvani, it implies that moon is in the Ashavani Naxatra at that moment. However sometimes it is also taken to imply that sun is in that Naxatra. For example when it is said that lord Krishna was born in Rohni Naxatra, it is meant that at that moment the moon was in Rohni Naxatra. However when it is said that the rainy season starts in Aadra Naxatra then it is meant that rainy season starts when Sun is in that Naxatra. The time of the ending of each Naxatra in a year is mentioned in Panchang of that year.

Word 'Naxatra' is also used for a star. Some star clusters are also called Naxatras especially those star clusters which are located along the path of the moon in the sky. The names of these star clusters have been assigned to Rashis, such as Ashwani Rashi, Bharni Rashi etc. It appears that in the hoary past names Ashwani, Bharni stood for star clusters in which moon was located during its motion around the earth. Later on for convenience in calculations, a Naxatra was taken to mean exact 27th part of ecliptic.

Yog : Yog is the sum of Bhagansh (longitudes) of the sun and the moon at a given instant. It has been assumed that Yogs will be 27 in all and each has been assigned a name such as Vishkambh, Priti etc. In order to determine yog, the bhagansh of the sun and the moon are added and then expressed in terms of kalas and then divided by 800. Adding one to the integer part of the quotient determines the serial number of Yog. It is then assigned the name given to this serial number. For example if the quotient turns out to be 1.372 then yog number is 2 and at that time Yog will be Priti. In Panchangs end point of each Yog is also mentioned.

Karan: Half a Tithi is called Karan. For example the first half of Pratipada Tithi is called Balav and the second half Caulav. However there being 60 halves of 30 Tithis, and so the names of Karans should have been sixty. However it is not so. Their names are less and there is a rule to assign a specific name from amongst these to a particular Karan.

Lagan: Lagan at a given moment indicates as to which part of the ecliptic is crossing the eastern part of horizon at that moment. Lagan essentially serves the same purpose as hour.

Month (Mas): All the five terms listed above change from day to day. Therefore to specify the time of the happening of an event, in addition to the above five terms month and year have also to be specified. Hindu Panchangs use lunar months. Their number is normally 12 in a year. Duration of a month is from one new moon (full moon) to the next new moon (full moon). However from time to time an year is made to have thirteen months so that months keep pace with the seasons with which these are normally associated and the same seasons fall in the same months from year to year. There are rules for adding this additional 13th month to an year. This extra month is termed adhikamas (additional month). In Gregorian calendar the start of months has no relationship with the full moon or new moon. The number of days in months have been fixed arbitrarily around 30 so as to make a total of 365 days in an year of 12 months. (May be it is because of the fact that because of the harsh weather conditions in Europe in most part of the year, it was not easy for a lay man to observe the sun during the day and moon and stars at night). Hijri calendar followed by Muslims had its origin in the Arab world, where weather being clear most of the year it is convenient to observe the sun, the moon and stars. That is perhaps why in Muslim Hijri calendar, an year has been taken to consist of exact twelve lunar months. As a result of this, there is no permanent relationship between the months and seasons. Festival of Id falls in different seasons in different years. This is their religious calendar. However in India Muslim rulers followed another year for revenue purposes. This was called `Phasli year` which was essentially of same duration as a solar year.

Names of lunar months as well as additional month (when it falls due in a particular year) are mentioned in Panchangs. The ecliptic has been divided into twelve parts. Each part is called a Rashi. As long as the sun is in a particular Rashi it is that month. As a result a month can begin at any time of the day or night. However for public convenience a new month is considered to begin with the first sunrise after the sun enters that Rashi. Names of Rashis are: Mesh, Vrish, Mithun, Kark, Singh, Kanya, Tula, Vrishik, Dhanu, Makar, Kumbh and Meen. Sankranti is the instant when sun transists from one Rashi to the next Rashi. For astrological purpose the duration of a month is from one Sankaranti to the next. Number of days in a month can be any from 29 to 32. This is so because on account of non-uniform angular velocity (because of Kepler's laws of orbital motion), the time that sun spends in a Rashi varies from Rashi to Rashi.

For astrological purposes in most parts of northern India, a lunar month is used. This is the time from one full moon to the next full moon. For civil purpose a new month is supposed to begin from the first sun rise after full moon. However in Southern India lunar months are counted from one new moon to the next new moon. (This was also the rule in earlier times in north India as well.) At present the names of months in north and south India are identical only in Shukal Paksh (waxing moon). In Krishna Pakash (waning moon) name of month in north India is one ahead of the name of the month at that time in south India.

Names of twelve lunar months have been selected from amongst the names of 27 Naxatras. These have been so selected that these are more or less at equal angular distance from each other. Name of a month is usually the name of the brightest star in the cluster in which the moon is located when full moon of that month takes place. For example month 'Chaitra' is that month in which full man takes place when moon is near the star Chitra in the stellar cluster by that name.

Number of Days in a Month: Duration of a month is taken to be the time between two consecutive full moon days. However when moon is precisely full moon is not easy to decide. If moon appears full now it was also appearing full sometime earlier and will also be appearing full sometime later as well. Therefore assuming a month to be of 30 days (even though precisely it is about 29 and a half days) may not create noticeable discrepancy for a few months. However with the passage of time it will be noticed that regarding each lunar month to be of thirty days will gradually result in the start of a new month being not on a full moon day but from a much later day. This must have lead learned pundits of the distant past to conclude that for the length of a lunar month value around 29 and a half solar days would be more appropriate to ensure that each new month starts on a full moon day. To avoid this fraction part in the length of each month, some months were assigned 30 days and others 29 days.

However, fixing length of some months as of 29 days and others 30 days was done only for civilian day to day work. Orthodox pundits who believed in exact mathematical calculations rather than observations, stuck to regarding the start of the next month exactly at the time of full moon which is obtained through calculations. Pundits and Jyotish Shartris still stick to this practice while preparing horoscopes. As they say, whereas Hindus give precedence to calculations over observations, it is the other way around for Muslims. Muslims give precedence to observations over calculations. That is why the month of Ramzan and Id are decided exclusively on the basis of the sighting of the new moon. Even though it is good that pundits go by calculations rather than observations, the unfortunate part is that in calculations they still use the rules framed thousands of years back which according to present day observations are not very accurate. In Panchangs and Jantaries, positions and times of rising and setting of the sun, the moon, the planets and important stars and star clusters are mentioned for each day of the year as obtained through calculations. However these are not exact. Exact positions and timings of rising and setting of the sun, the moon, the planets and important stars and stars cluster are now published each year in what are known as Nautical Almanacs (These are so named as these were earlier prepared for the use of sailors of ships for locating their position on high seas). These values are more accurate and precise. However astrologers and pundits still stick to their earlier rules of calculations even though these do not provide accurate results. In fact the errors keep on accumulating from year to year.

The situation is still not that alarming for day to day purposes as the difference is not more than two hours in majority of the cases. For instance telling full moon to be two hours this way or that way of the actual time may not make much difference. However such a difference in the time of the start or end of an eclipse can create a lot of resentment in the public. In view of this while making predictions about the start and end of an eclipse, surprisingly, the learned pundits have no qualms in using modern more accurate available data.

Number of Months in an Year: It must have been observed that seasons change periodically. There is first spring, then summer, then autumn, then winter which is again followed by spring. This happens regularly and a cycle of seasons is completed in about twelve months. This must have lead earlier civilizations to conclude that besides periodic changes of day, night, and the days between a full moon and next full moon; there is also a periodic change of seasons which happens after every twelve months. This must have led them to regard twelve months as the length of a still bigger unit of time which is now called year.

Later on it must have been realised that keeping each year of twelve months and each month of 30 days gradually leads to seasons not keeping pace with the months. This must have lead to search for appropriate corrections so that an year is of around 365 days and the length of each month is around 30 days. It is now being done in different manners in Hindu and Gregorian calendars. However Muslims calendar still sticks to the convention of an year being of 12 months and each month of around 30 days (from one new moon to the next). As a consequence it is noticed that where as Hindu and Christian festivals keep pace with seasons, it is not so in the case of Muslim festivals. Some years we have Id in summer, in some years in winters, in some years in autumn and in some years in spring.

Realtion between different units of time: Although for day to day work it is normally assumed that a month has 30 days and 12 months constitute an year, however in reality that is not so. The reason being that time from one new moon to the next new moon is not exact number of days (it is about 30 days) and the time of one complete cycle of seasons is again not exact 12 months of 30 days. In fact finding relation between these three units of time is often regarded as the actual beginning of the study of the subject of astronomy. If one finds a mention of the number of days in a month and the length of an year, then one can use these to estimate as to how for the knowledge of astronomy had progressed in that period.

Rigveda is the oldest known book of not only India but perhaps of the entire world. It is mentioned at one place in this book that in those days an year was considered to be of 12 months and each month of 30 days. However the learned Rishis of the yore must have noticed some lacuna in it, because if one starts counting from a new moon day, then after 12 months of 30 days it is noticed that it is not a new moon. How ever for day to day purpose, an year of 12 months and each month of 30 days might have roughly served the purpose.

Introduction of an additional month (Adhika mas also called Adhikmas/Malmas/Purshottam mas) from time to time is an effort to establish in the long run a relationship between a solar year and lunar months. To appreciate this it is important to keep in view that the number of days in lunar and solar months are different. There are around 365 1/4 days in a solar year. As a result average length of a solar month is (365 ¼)/12 i.e around 30 days and 10 and a half hours. This is more than the length of a lunar month which is about 29 ½ days. Therefore it is possible that two new moons may occur in the same solar month. Two consecutive months that happen with their new moons occurring in the same solar month are given identical names. The time between such two new moons that occur in the same solar month is called 'Adhikamas' or Malmas. In this period there is no Sankranti. In such a case an year has thirteen lunar months. This helps in making necessary corrections in lunar calendar periodically to ensure that in the long run same seasons occur in the same months. With this correction, the maximum difference that can occur in relationship between months and seasons is not more than fifteen days (plus or minus). This correction is done periodically in the lunar calendar to ensure that in the long run same seasons occur in the same months.

It is also to be noted that the time that sun spends in each Rashi is not identical. As a result there are solar months whose length is less than even 29 ½ days. It is possible that in such a short solar month no new moon may take place. In such a case a lunar month may not occur in that solar month. As a result the associated lunar month will not appear in the calendar of that year. However compared to the occurrence of additional lunar month the disappearance of a lunar month is rather a rare phenomena.

Year: Most important unit of the measure of time is year. It is the time of one complete revolution of the earth around the sun. In Indian languages, year is known by several alternative names such as 'Varsh', 'Savantsar', 'Vatsar', 'Abd', 'Hayan', 'Sama', 'Shard', 'Vasant' etc. Most of these names have relationship with one season or the other. For example 'Varsh' is related to 'Varsha' (rainy season). 'Vasant' is spring season, 'Shard' implies winter, and 'Savantsar' means a period in which each season occurs once etc. Of these the most commonly used name of the year is 'Varsh'. This clearly indicates that in India months in a year were meant to keep pace with the seasons. So that next year always begins in the same season. This obviously implies that in India, an year has generally implied a solar year (time of one complete revolution of earth around the sun). This is further supported by the fact that over the ages an year is divided into two parts: 'Uttrayan' and 'Dakshanayan'. Uttrayan is that part of the year in which sun moves north wards and 'Dakshanyan' that part of the year in which the sun moves south wards.

However our ancient astronomers were not aware of the recession of spring equinox (also known as first point of Aries, the point where path of sun (ecliptic) in the sky crosses celestial equator). Later astronomers were aware of it but were not sure whether this motion is always in the same direction or it is oscillatory about a central position. As a result they could not differentiate between solar year and stellar year. (The first is the time of revolution of earth around sun with respect to verinal equinox (the first point of Aries) and the second is the time of revolution of the sun with respect to some fixed star). As a result even though astronomers in India wanted to measure the length of a solar year, they in reality were measuring the length of a 'stellar year'. According to Surya Siddhanta, an year is of 365 days 6 hours 12 minutes and 36.65 seconds. However according to modern day measurements, the length of a solar year is 24minutes less where as the difference between a solar year as per Surya Siddhanta and a Naxatar (stellar) year is only 3 minutes.

Unfortunately even now Panchang markers in Indian are not unanimous. The advanced ones amongst them have started accepting the present day more accurate value of the solar year. However the orthodox ones still cling to the old value which is in reality the length of a 'Naxatar Year'. Another point of disagreement is the exact location of the first point of Aries.

A point to be kept in mind is that in case the adopted length of an year is not a solar year, then with the passage of time it will not be possible for seasons to keep pace with original months in which these occurred. These days months of Savan and Bhadon are associated with rainy season. However if the length of the year is adopted to be same as per Surya Siddhanta, then after a few thousand years it will be winter in these months. A difference of around 25 days has already taken place since the time of Kalidasa. (That is why it is noticed that the rainy season now generally starts mid Ashar). Difference since Vedang period is now in fact over 44 days (around one and a half month).

Years have to be numbered in some chronological order. For this different conventions have been used. One that is most commonly accepted is the start of Kaliyuga which is midnight between 17th and 18th February 3102 B.C. According to this the year 2015 C.E is the year 5117 of Kali Yuga. Common Era or (Christian Era) CE is now also being used. Other starting dates in common use are Vikrami Samwat and Saka Era.

These five parts of the Panchang enable learned Pandits to determine auspicious and in auspicious periods and fix dates of festivals etc. Indian Panchang has a scientific base and it takes care of both lunar and solar months. However a drawback of this Panchang is that a common person who is not well versed in the intricacies that go into the making of a Panchang, cannot easily make an effective use of it. Ancient Panchangs and Kundlis have proved helpful in determining the chronological order and precise occurrences of various events of importance that happened in the past. But the unfortunate thing is that the whole of India does not follow the same Panchang. (Keeping in view the vastness of the country and lack of quick means of communication in the past, it was perhaps natural that different regions of India had different panchags, and traditions once established die hard).

3. Efforts for a Unified Pan India Panchang

There are a number of Panchangs prevalent in India. As a result there is often a lot of confusion in the mind of general public as to the day of celebration of a religious festival. In order to design a scientific based Panchang which could be universally followed though out the country, in 1947 soon after independence, Govt of India set up a committee to review the different Panchangs prevalent in different parts of the country and keeping these in view to come up with a rational scientific based Panchang which could be adopted throughout India. Committee consisted of eminent scientists in the field. Its chairman was eminent Physicst Dr. Meghnath Saha. Other members included Dr. Gorakh Prased, Dr. Daphtry and Dr. Nirmal Chand Lahary. Committee reviewed the panchangs prevalent in different parts of the country. It also invited suggestions and views from public and considered the views of persons who responded. Based on all this it came up with the following recommendations:

(i) Length of an year be taken to be 365.2422 days. This will ensure for times to come that months keep pace with the seasons as of now. (No effort was made to rectify earlier errors.)

(ii) Year will begin from spring equinox (i.e March 22)

(iii) Second to sixth months of the year will be of 31 days each. Remaining seven months will be of 30 days each. In the case of a leap year seventh month will also be of 31 days. Leap year will be the same year as it is in the prevalent Gregorian calendar.

(iv) New day will be assumed to start at midnight.

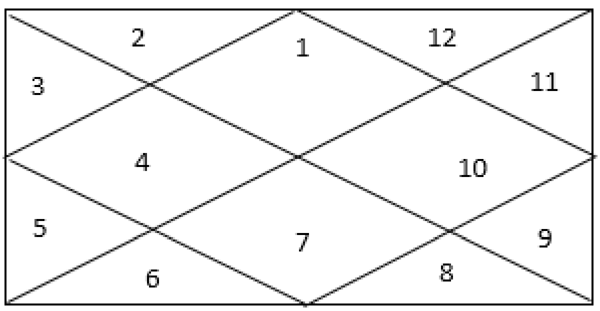
(v) The standard Indian time(IST) will be with respect to Ujjain and 5 and a half hours ahead of Greenwhich Mean Time(GMT).

(vi) Saka era will be followed. (Its start is 79 CE when Persian tribes invaded northern India).

Government of India formally accepted these recommendations and commenced its use for official purposes. However habits die hard and unfortunately it has not got the public response that it deserved. Pandits and astrologers still stick to their old conventions unmindful of the fact that these have now lots of errors. We hear of reference to Saka Era related calendar dates only on official functions and each day in the morning on all India radio and Doordarshan .

4. Horoscope (Kundli)

Kundli is a rectangle divided into twelve boxes by drawing diagonals and two lines parallel to each diagonal as shown in the following figure. Assigning number 1 to the topmost middle box, these boxes are numbered from 1 to 12 in anticlockwise direction. Each box is associated with one of the twelve rashis as per its number. Box1 represents the rashi which was crossing the eastern horizon at that instant.



For preparing the horoscope of a person (usually at the time of birth), the positions of sun, moon, five planets (Mercury, Venus, Mars, Jupiter, Saturn) and Rahu and Ketu are depicted in these 12 boxes as per their location in various Rashis at that instant .

Astrologers use these kundlis prepared at the time of birth for making future predictions. However, besides this, it has another important use for the historians. Janam kundli of a person can be used to determine the time and date of birth of that person.

5. Astrology

Sometimes people confuse astrology with astronomy. In fact the Sanskrit term for both is `Jyotish. Astronomy essentially deals with the observation of the positions of heavenly bodies at different times and from different places, and maintaining records of this data and its scientific analysis to draw conclusions of practical significance. Astrology deals with the preparation of horoscopes of individuals at the times of their births and their use in making predictions about their future.

Humans have always felt an urge to know their future in advance and if possible to make it as per their wishes. Disciplines such as astrology, palmistry and numerology have evolved over the years with the help of which some persons claim to predict future and also propose remedies to ward off the predicted ill effects.

Astrologers claim that they can predict future happenings in the life of a person on the basis of the horoscope prepared at the time of his/her birth. History has records of astrologers predicting future of new born princes on the basis of the horoscopes prepared at the time of their births. Even now in modern times of science and technology, a large majority has an inbuilt faith in astrology and its predictions. In fact its popularity in India is growing day by day. We now have several T.V. programs where pundits each day predict future of persons born in different Rashis.

A question that naturally arises in the mind is that what is after all the authenticity of such astrology based predictions? Are these exact and precise, or should such predictions be taken with a grain of salt, or should these be altogether rejected? Personally I am of the view that such predictions are to an extent statistical in nature. When people noticed that astronomers through their calculations could accurately predict the time and duration of the occurrence of an eclipse which is to happen in future, they started believing that perhaps through such calculations they could also predict future happenings in the life of a person.

Being persistently pressed for this, it is possible that the learned pundits started surveying the records of happenings in the lives of individuals having identical positions of planets in their birth horoscopes. Based on a careful analysis of such data, they might have come up with certain identical types of happenings in general in the lives of persons with identical birth charts, and started using such information to predict the future of persons. With the passage of time, this art must have gradually evolved and improved through experience. In fact now we have voluminous documented books on astrology.

Astrology has two components. One is the preparation of horoscope at the time of the birth of a child. The second is the prediction of future happenings in the life of the child on the basis of this horoscope. Of these two, the first is scientifically based. However the same can not be said about the second. Can the future of a person be predicted based on his/her horoscope? Some believe it can be. However there is no rational or scientific base for it except that such predictions are to an extent statistical in nature based on the study and analysis of happenings in the lives of individuals of the past with identical horoscopes. Such predictions should be accepted with a grain of salt and should not be expected to be hundred percent correct. Just as even when weather man says that there is great possibility of its raining on a particular day and still it may not rain, the same is true of predictions based on horoscopes. Moreover, as mentioned earlier, in view of the inaccuracies in the computed positions of various planets based on conventional rules of the past that are still followed in the preparation of horoscopes, the indicated positions of various planets in the horoscope may not be fully correct. As a result even if it is assumed that the methodology adopted in interpreting a horoscope is correct, the predictions based on it may still not be fully correct.

A still more perplexing component of reading of a horoscope is that the learned pundits not only predict the future but also offer remedies to offset the ill effects of unfavorably placed planets. The effect of the suggested remedies seems to be more of a psychological nature. After having performed the suggested remedial measures, a person starts feeling that the predicted adverse effects will either not happen at all or at least their predicted ill effects will get considerably mitigated. And of course the pundits charge hefty fees for preparing and reading horoscopes , and for performing remedial measures. In fact this is their main source of income. By the way, is there any one at the time of whose birth all the planets were in favorable position? Moreover when suggested remedial measures do not work, the common explanation is that the predicted ill effects were so severe that even the performed remedial measures could not prove fully effective (just as in some diseases remedies do not work). It is not only in astrology but in fact in every field of human activity that shrewd and unscrupulous persons exploit the innocence of common people and befool them for their self interest.

Personally I am of the view that predictions based on horoscopes (or for that matter by any other means) should not be regarded as gospel truths. These may at the most be regarded as statistical in nature. Just as when weatherman says that it is likely to rain, it is advisable to go out with an umbrella even though it may not rain, the same can be said about astrological predictions. However the dark side of all this is that where as a bright predicted future may make one lethargic with the result that the predicted bright future that could have happened may not happen, the prediction of an adverse future may make one lose hope and courage and make the predicted adverse future still more bleak.

Actually what should happen is that where as the prediction of a bleak future should caution one to be well prepared to face it with confidence and fortitude, the prediction of a bright future should goad one to work still harder to make it still more brighter. As they say future is after all future and no one can predict it with certainty. In fact through ones effort it can even be changed (and that is what astrologers promise when they suggest remedies).

In this context I am reminded of Dr. G.S.Anand, an old friend of mine. When I came to know him, he was just a high school pass young man working as a clerk in my father`s office. He belonged to a well off family of pre partition India, and had lost his father during the partition.Being the eldest male, he was forced to take up job to support his family. One day a palmist came to their house and his mother asked the palmist to read her son`s hand and predict his future. The palmist after gazing at the hand of the boy remarked that the future of this young man was just so so, and that he would neither be able to undertake higher studies nor go much further in life. On hearing this, my friend remarked that he would prove the palmist wrong. And that he did. While doing service in government offices, he completed part time graduation, post graduation, law and later on even Ph.D.! Subsequently he became a lecturer and later a reader in a university and also earned reputation as an eminent scholar in his field. As they say through sustained effort and hard work one can change luck and move mountains.

Appendix-II

SIDDHANTAS, KARNAS AND KOSHTAKAS

Siddhanta literally means the established end result. Siddhanta astronomy came to India as a result of interaction with the Greece in post Alexandrian period. The first leading figure who worked in this direction was Aryabhata-I. He compiled his siddhantic work titled Aryabhatiya in 499 A.D. The prime object of these works has been to present to the user the latest available astronomical data about the sun, the moon, the planets and the stars in an easy to use format. Besides Siddhantas, there are also an other type of astronomical works which are called Karnas. If Siddhantas are considered as text books on astronomy, then Karnas can be regarded as made easy type help books. They provide the user practical rules that assist him in carrying out computations mentioned in Siddhantas. Another note worthy difference between the two is that where as in a Karna, a contemporary epoch is chosen as reference origin for time, in Siddhantas the starting reference point of time is the beginning of a Kalpa or a Yuga.

As early as 1000 A.D., Al-Borouni (973-1048) noted that there existed in India a large number of Karna works. In fact the development of memorable algorithms for preparing reasonably accurate planetary tables was regarded as an intellectual feat of high calibre. As a by product solutions were found for many intricate mathematical equations. Centauries later, this attracted the attention of European mathematicians. In fact the last of the classical Siddhantic astronomers such as Chandra Sekhar Sinha (1835-1904) lived right into the twentieth century. Karna activity also continued right up to 19th century. Ganesh Daivajna's Graha-Laghav (1520) has been one of the most influential Karnas.

It may be noted that ancient Indian astronomical effort was primarily oriented towards society rather than the sky. Its main objective being to prepare almanacs to pin point auspicious occasions for social and religious purposes and help astrologers in preparing horoscopes for making predictions. As a result, besides Siddhantas and Karnas there are also tertiary texts called Koshtakas (or Sarnis). These provide ready to use specific astronomical tables as reference tables for use by astrologers and makers of panchangs and almanacs. Even though many of these texts are attributed to their actual authors, in many cases these are often passed off as heavenly revealed.

Important Siddhantas and Karnas are summarised in Tables 1 and 2. The lists are representative and not exhaustive. Asterisks in table 1 denote the appearance of same in table 2 and vice-versa. In order to indicate the period of the work, the year of the actual writing of the work or the date of birth or the life period of the author (whichever is authentically available) is given.

Table 1: Important Siddhantas

Year (A.D.)	Author	Place	Work
499	Aryabhata	Patna	Aryabhata-Siddhnata Aryabhatiya
505	Latadeva		Redactions of Saura-, Romaka-, Paulisha-Siddhanta
628	Brahmagupta	Bhillamala, Rajasthan	Brahma-Sphuta-Siddhanta
629	Bhaskara-I	Valabhi, Gujarat	Maha-Bhaskariya , Laghu-Bhaskariya
748	Lalla	Dasapura, Malwa	Shishya-dhi-Vriddhida
800	Anon		Surya-Siddhanta
904	Vateshvara	Vatanagara, Gujarat	Vateshvara-Siddhanta
953	Aryabhatta-II		Maha-Siddhanta
1000-1050	Shripati*	Rohinikhand,(south.of Ujjain)	Siddhanta-Shekhara
1150	Bhaskara- II*	Vijjalavida, Bijapur	Siddhanta-Shiromani
1444	Nilakantha Somayaji	Kundapura, Kerala	Tantra-Sangraha
1503	Jnanaraja	Parthapura, Godavari	Siddhanta-Sundra
1550-1621	Achyuta Pisharati*	Kerala	Sphuta-Nirnaya-Tantra
1628 1639	Nityananda -do-	Kurukshetra -do-	Siddhanta-Sindhu Siddhanta-Raja
1646 1658	Munishvara Kamalakara	Varanasi Varanasi	Siddhanta-Sarvabhauma Siddhanta-Tattva-Viveka

Table 2: Important Karanas

Year	Author	Place	Work
505	Varahamihira	Ujjian	Pancha-Siddhanta
665	Brahmagupta*	Bhillamala, Rajasthan	Khanda-Kkhadyaka
683	Haridatta	Kerala	Graha-Chara-Nibandana
689	Devacharya	Kerala	Karana-Ratna
932	Manjula (or Munjala)	Prakash-Pattana	Laghu-Manasa
1000-1050	Shripati*		Dhi-Kotida-Karana
1092	Brahmadeva	Mathura	Karana-Prakasha
1099	Shatananda	Puri, Orissa	Bhasvati-Karana
1183	Bhaskara- II*	Vijjalavida, Bijapur	Karana-Kutuhala
1316	Chakreshvara Mahadeva	Rasina, Godavari	Mahadevi
1282/1306.	Vararuchi	Kerala	Vakya-Karnan
1367	Mahadeva	Trymbak, Godavari	Kamadhenu-Karana
1430	Parameshvara	Alattoor, Kerala	Drig-Ganita
1375	Ishvara		Karana-Kantirava
1417	Damodara		Bhatta-Tulya
1496	Keshava	Nandgaon, Maharashtra	Graha-Kautuka
1530	Chitrabhanu		Karanamrita
1500-1560	Shankara Variyar	Kerala	Karana-Sara
1520	Ganesha Daivajna	Nandgaon, Maharashtra	Graha-Laghava
1578 1578	Dinakara		Kheta-Siddhi Chandrarki
1593	Achyuta* Pisharti*	Kundapura,Kerala	Karanottama
1590	Ramachandra-Bhata	Delhi	Rama-Vinoda
1608	Vishnu	Golagram, Godavari	Suryapaksha-Sharana-Karana
1589	Dhundhiraja	Parthapura, Godavari	Graha-Mani
1619	Nagesha	Gujarat	Graha-Praboha
1653	Krishna	Konkana	Karana-Kaustubha
1704	Jatadhara	Sarhind, Punjab	Phatteshasha-Prakasha
1660-1740	Putumana Somayaji	Shivapura, Kerala	Karana-Paddhati
1763	Nandarama Mishra	Kamyaka-vana	Grahana-Paddhati
1760	Shankara	Dvarka, Gujarat	Karana-Vaishnava
1714	Manirama		Graha-Ganita-Chintamani
1781	Bhula	Narmada	Brama-Siddhanta-Sara
1823 1832	Shankara Varma Jyotiraj	Katattanadu, Kerala Nepal	Sad-Ratna-Mala Jyotiraja-Karana

Appendix-III

OBSERVATIONAL INSTRUMENTS OF INDIAN ASTRONOMY

In India there has been greater stress on computational aspects rather than observational aspects of astronomy. Therefore very few astronomical observational instruments have been used. Here we list in brief some of the instruments of Indian Astronomy which have been in common use in the past.

Gnomon: Gnomon was a simple device in common use for measuring the passage of time during day time. It is also known as Sanku. In this the shadow of a vertical rod is allowed to fall on a horizontal plane to ascertain the cardinal directions and the time of observation. It has been in use since long past and finds mention in the works of Varahamihira, Aryabhatta, Bhaskara, Brahmagupta and several others.

Yasti Yantra: Another simple observational instrument in common use has been Yasti-yantra. This is essentially a across staff. It is usually V-shaped and is meant for measuring angles with the help of a calibrated scale attached to it. It has been in use since the time of Bhaskara -II.

Ghatti Yantra: Ghatti Yantra has been in use in India for measuring the passage of time in day as well night. It consists of a pot with a fine calibrated hole at its bottom. This pot is placed in a tub of water. The gradual filling of the pot with water entering it from the hole at its bottom measures the passage of time. This simple time measuring instrument has been in use since times immemorial and has been infact in use even up to a not very distant past.

Gola Yantra: Gola Yantra (The armillary sphere) has been also in use in India since early times. It finds its mention in the works of Aryabhata (476 CE). Goladipika is a detailed treatise dealing with globes and armillary spheres. It was composed between 1380-1460 CE by Paramesvara. According to Ohashi (2008), the Indian armillary sphere is based on equatorial coordinates unlike the Greek armillary sphere which is based on ecliptic coordinates. In fact the Indian armillary sphere also has an ecliptic hoop. Probably the celestial coordinates of the junction stars of the lunar mansions were being determined with the help of the armillary sphere since the seventh century or so. There is also a model of celestial globe which is kept rotating by flowing water.

Phalaka Yantra: A device called Phalka yantra was invented by Bhaskara-II. It consists of a rectangular board with a pin and an index arm. This device was used to determine time from the sun's altitude.

Kapala Yantra: Kapala Yantra was essentially an equatorial sun dial type instrument used to determine the sun's azimuth.

Kartari Yantra: Kartari Yantra (Astrotable) combined two semi circular board instruments to give rise to a 'Scissors like` instrument. This instrument had come from the Islamic world and finds its first mention in the work of Mahendra Suri, the court astronomer of Feroz Shah Tughluq (1309-1388 CE). Astrotable finds further mention by Padmanabha (1423 CE) and Ramachandra (1428 CE) as its use grew popular amongst astronomers in India.

A nocturnal rotation instrument was invented by Padmanabha. It consisted of a rectangular board with a slit and a set of pointers with concentric graduated circles. Time and other astronomical parameters could be calculated by adjusting the slit to the directions of stars α and β Ursa Major. Its back side was made a quadrant with a plumb and an index arm. Thirty parallel lines were drawn inside the quadrant and trigonometric calculations were done graphically after determining the sun's altitude with the help of the index arm.

Seamless celestial globe: Seamless celestial globe was invented in Mughal India, specifically in Lahore and Kashmir. It is considered to be one of the most impressive astronomical instruments and a remarkable feat in metallurgical engineering. Even up to 20th century it was believed by the metallurgists that it was technically not feasible to create a seamless globe. It was in 1980's that Emilie Savage-Smith discovered several celestial globes with out any seams in Lahore and Kashmir.

The earliest seamless globe is believed to have been invented by Ali Kashmiri-ibn-Luqman in (1589-90 CE) during the reign of Akbar. Another was produced in (1659-60 CE) by Muhammad Salih Tahtwai with Arabic and Sanskrit inscriptions. This was perhaps the last one of its type which is believed to have been produced. These are perhaps the only examples of seamless metal globes. Mughal metallurgists had developed a method of lost wax casting to produce such globes.

2. Instruments in Jai Singh's Astronomical Observatories

Jai Singh's astronomical observatories at Jaipur, Delhi and Benaras have a number of astronomical instruments which are mostly in mortar. Some of these are:

Yantra Raj: This is helpful in doing astronomy related computations fast.

Smrat Yantra: It is used for determining the position coordinates of sun and other heavenly bodies.

Jai prakash Yantra: This is useful in determining the right ascension and declination coordinates of the sun.

Ram Yantra: It is used for determining azimuth and altitude of heavenly objects.

Dignash Yantra: It is used for determining the location of a heavenly object.

Nadi Viley Yantra : It is helpful in deciding whether the observed position of the sun or star is to the north or south of the celestial equator.

Dakshino-Vrit-Yantra : It measures position coordinates(azimuth and altitude) of stars.

Sashthansh Yantra : It is meant for finding the altitude of the sun.

Mishra Yantra : It helps in transferring observed data of the observatory to data as it would have been observed at that time from some other standard reference position such as Ujjian. It is to an extent similar to the Samrat Yantra.

3. Texts on Instrumentation

Even though names of various astronomical instruments with brief description had been appearing from time to time in Sanskrit literature since times immemorial, no specific text exclusively devoted to instrumentation written in the distant past is known to exist. Mahendra Suri, the head astronomer in the court of Feroz Shah, prepared in 1370 CE a monograph on astrolabe titled Yantra-raja. This was perhaps the first Sanskrit work exclusively devoted to astronomical instrumentation. Later many commentaries were written on it. In around 1400 CE, Padmanabha described an astrolabe with a design different from that of Mahendra Suri. Padmanabha also gave a description of an instrument called 'Dhruva-Brahamana` which measures time by observing the star group 'Solar fish' that includes Alpha and Beta Ursa Minor.

In eighteenth century Raja Jai Singh wrote a treatise on instruments titled `Yantra-prakara`. Its writing was completed by 1724 CE. However some more additions were being made to it as late as 1729 CE. Jai Singh`s astronomer, Jagannatha, translated it in 1732 CE. Nasir-al-Din–al-Tusi's (1201-74) Arabic version of Potlemy's Almagest was translated into Sanskrit under the title `Samrata-Siddhanta`. This also had a supplement that described various other instruments.

In the accompanying table are listed Sanskrit texts that are exclusively devoted to astronomical instruments.

Instrumentation texts in Sanskrit

Year	Author(Place)	Work	Instrument
1370	Mahendra Suri (Delhi)	Yantra-Raja	Astrolabe
1400	Padmanabha	Yantra-Kiranavali	Astrolabe
1428	Ramachandra (Sitapur)	Yantra-Prakasha	Miscellaneous.
15th cent.	Hema (Gujarat)	Kasha-Yantr	Cylindrical sundial
1507	Ganesha Daivajna	Pratoda-Yantra	Cylindrical sundial
1550-1650	Chakradhara (Godavari)	Yantra-Chintamani	Quadrant
1572	Bhudhara (Kampilya)	Turiya-Yantra-Rakasha	Quadrant
1615	Jambusara Vlshrama(Gujarat)	Yantra-Shiromani	Miscellaneous.
1720	Dadabhai Bhatta	Turiya-Yantrotpatti	Based on Chakradhara's work
1688-1743	Jai Singh Sawai (Jaipur)	Yantra-Prakara Yantraraja-Rachana	Miscellaneous
1690-1750	Jagannatha (Jaipur)	Samrata-Siddhanta (1732)	Translation of Almagest with supplement on instruments
1700-1760	Lakshmipati	Dhruva-Bhramana-Yantra, Samrata-Yantra	As in the title
1700	Nayansukha Upadhyaya	Yantraraja-Risala-Bisa-baba or Yantraraja-Vichara-Vimshadhyay	Astrolabe (Translation. of MS by Nasir-al-Din al-Tusi, 13th cent., Iran)
1722	Nandarama Mishra (Kamyakavana), Rajasthan)	Yantra-Sara	Miscellaneous
1782	Mathuranatha Shukla (Varanasi)	Yantraraja-Ghatana	Astrolabe
1800	Chintamani Dikshit	Golananda	Miscellaneous

ABOUT THE BOOK

The object of the author in writing this book is to familiarize the reader with the gradual evolution and growth of astronomy in the Indian subcontinent over the ages. Starting with the status of the subject in the hoary distant past, the reader is made aware of its gradual evolution over the centuries, its interaction with the astronomies of different parts of the world, finally leading to its present status. The reader is also made aware of the present status of our knowledge of astronomy and cosmology. In an appendix, the reader is also introduced to the basic essentials of Panchang, Horoscope, and Astrology.

ABOUT THE AUTHOR

Prof. Chander Mohan was born on October 8, 1939 in Jehlum, (Punjab province of pre-partition India).His early primary school education was in a village school of pre-partition days. The family migrated to India in August 1947.

Prof Chander Mohan obtained his B.A. (Hons.) in Mathematics (1957), and M.A. in Mathematics (1960) from Punjab University and Ph.D. from Roorkee University in 1967. He has been actively engaged in teaching and research since 1960 . From 1964 to 2000, he worked as lecture, reader and professor in Mathematics department at Roorkee University (now IIT Roorkee). He was also the head of the Mathematics department from 1995 to 1999. While working at Roorkee University, he visited England in 1973 under British Council `Exchange of Younger Scientists Program, and worked on deputation with Baghdad University Iraq from 1976 to 1979. After retirement from Roorkee University in 2000, Prof. Mohan worked as professor and dean Amity School of Computer Science, Noida from 2000 to 2002. From 2002 to 2004, he worked as professor and head mathematics department in IILM College of Engineering, Greater Noida. Since 2004 he is working as professor in the department of Computer Science and Engineering in Ambala College of Engineering and Applied Research, Devasthali, Ambala (Haryana).

Prof. Mohan has published over one hundred research papers in journals of international repute. He has also published six books. He is member of several technical and research societies and his autobiographical sketches have appeared in some national and international WHO`S WHO.

Ever since childhood, Prof. Mohan has been fascinated with astronomy. He studied astronomy as a subject in his masters program. His Ph.D. work was on theoretical Astrophysics. He also taught for several years , astronomy and astrophysics to undergraduate and post graduate students at Roorkee University. He has also guided some Ph.D. scholars in topics of Theoretical Astrophysics. He is a founder member of Indian Astronomical Society and a member of IAU (international Astronomical Union).