Archaeo-Astronomy[1]

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1. Summary

Archaeology is the study of ancient civilizations and their developments while astronomy, apart from being the study of skies – a study of location of Sun, Moon, planets and stars, is one the oldest sciences. Hence the imprint of astronomy can be found in ancient cave tools onwards. Astronomy is expressed in a variety of ways in different literature. However, it has never been exploited to create a separate window into the past. In the present paper, we discuss the possibility of using astronomy as an effective tool for archaeology and the ability and limits of such studies.

2. Introduction

Archaeology is conventionally studied by exploring the sites of ancient civilizations for physical evidence along with the language, literature etc. This has been a highly successful field of studies that has resulted in some truly inspiring insights into human evolution. However, this is a *post facto* study of what the civilisation left behind. On the other hand, the evolution of the civilisation itself takes a different path. The first to rise, of course is group hunting to group organisation, language, domestication of animals and eventual settling down of the civilisation. However, there is another parallel intellectual development that occurs as a civilisation grows, and that is the observation of the sky.

The first changes that any evolving civilization notices is the fact the Sun, Moon and stars are not constant in the sky and that the Sun rises in the East and sets in the West with a reasonably regular periodicity with one complete cycle taking a fixed amount of time. For the sake of convenience, in the remaining part of the article we will refer to this as a *day*. It also requires only a small number of observations that while the Moon's shape and period are more spread out, over 28 days, the moon returns to the same apparent location in the sky at the same fraction of the day and its apparent shape is also identical. From here onwards, a careful observer will begin to notice that the moon rises a fraction later each day and after that fraction completes half the day, the Moon begins to rise in the morning, rising earlier by the same fraction as it was setting later in the previous times. Gradually the civilization begins to notice that the stars are not distributed in a random manner but can be divided into specific patterns and that stars rise in the

[1] Based on the talk given at the Conference on "Indian Archaeology in the 21st Century" Asiatic Society, November 6, 2004. The original title of the talk was "Astro-Archaeology" to emphasize the importance of Archaeology in the subject matter but the fear that "Astro" may be mistaken for Astro*logy* instead of Astro*nomy* made me change the title.

same pattern over a long time. However, the absolute time of rise of a particular pattern is delayed every day by the *same amount for all the patterns*. Also, long period observations will show that the patterns rise at the same time after 365 days. Similar observations will relate the broad climate of the region to the rise of a specific pattern at Sunset or Sunrise. A more elaborate civilisation would note that even amongst these stars there are a few objects (five of the approximately six thousand stars that can be seen by an unaided eye) who seem to move, again with an apparently fixed speed. After this, only the observation of eclipses remains, to complete the observations of the heavens that span the field of observational Astronomy.

It is easy to see how, a civilisation settled for a short period of time will begin to associate Sun with warmth and give it the position of God. Also, the rising phase of the Moon and dying phase of the Moon would quickly get associated with fortnights and two fortnights, completing one complete cycle would form a month. Twelve such months would bring the Sun back to its original position, i.e. in the same constellation at Sunrise or sunset time. Once the civilisation takes notice of this, the calendar is born.

However, nature is not so simple. The Lunar month is not *exactly* 29 days, one year is not *exactly* 12 lunar months etc. and all this begins to add errors into the calendar as the time drifts.

This difference can be effectively exploited for archaeological studies and we will discuss how this can be achieved and we will discuss some examples of this from literature.

It is prudent to note that in the text below, we will attempt to list the different ways in which astronomy can be *used* for archaeology and do not indulge in any discussion on history of astronomy which is quite a different subject of its own importance. Also, the field of archaeoastronomy has been in existence for some time and several books and papers can be found on various aspects of this subject. However, most of this literature is confined to some specific aspect of the subject while the emphasis of this article is that by extending the field beyond a handful of loosely used ideas to a comprehensive field that will prove to be far more effective subject of study. Also, the field, in Indian context is not very well known and often restricted to study of the architecture of temples with respect to the local directions and equinoxes or interpretation of *shlokas*.

3. *Rashis* and *Nakshatras*:

In order to keep track of the night sky, the stars in the sky are divided into 88 different patterns called constellations. Of these 88 constellations 13 are the most important ones since they lie along the plane of the revolution of the Earth (and the entire solar system) around the Sun. This plane is called the ecliptic. As a result, the Sun and the planets *appear* to move through these constellations and these have special names of Zodiacal Signs (*Rashis*). Since the plane of revolution of the Moon around the Earth is slightly inclined (by 5^o) to the ecliptic, its motion is slightly different from that of the Sun and the

planets, that is, the Moon can be seen in constellations where the Sun and the planets do not venture. Indian Astronomy also has a special set of 27 special patterns of stars (this pattern is not identical to the standard 88 constellations) called *nakshatras* which define the movement of the Moon in the night sky. The Sun takes 1 year to complete 1 movement through all the *Rashi*'s while the Moon takes 27.3 days (sidereal period) to complete its movement through all the *Nakhatra*'s. The Earth rotates on its axis which is tilted to the plane of revolution and the axis or rotation points to the Pole Star. All the stars appear to rotate along a sphere whose axis of rotation is defined by the Earth's own axis of rotation, or the Pole Star in the night sky. The pole star never rises or sets at any location on earth and the altitude (angular height from horizon) of the Pole star from the north defines the Latitude of the place. The closer one stays to the pole, (i.e. at higher latitudes), more and more constellations appear never to rise or set and are circumpolar to the Pole star which appears higher and higher in the sky, till at the Pole itself it appears overhead. For example, at the North Pole the entire star pattern is circumpolar and no stars rise or set. At the equator, the pole star remains at the horizon and all stars (except the Pole star) appear to rise and set. The Pole star is not visible in the southern hemisphere. An interesting consequence of this is that the appearance of the zodiacal constellations is different at different latitudes and hence the descriptions of shapes of constellations are *latitude dependant.*

4. Some useful periodicities

Moon, Sun, planets and stars are not fixed objects in the universe. Locations of these objects in the sky vary with different periodicities which can be effectively used for archaeological purposes. Some useful periodicities of various objects are:

4.1 Earth: While we assume the earth to be a constant entity it goes through several changes which are useful for dating archaeological and palaeontological objects. These are:

4.1.1 Earthquakes: These changes can be random or due to proximity to volcanoes or some local faults and in that case detailed studies of local crust are required to exploit the information. More important are the earthquakes along the fault lines of plate tectonics. These allow generalised studies of large areas such as Himalayas which have been exploited very effectively.

4.1.2 River diversions by earthquakes: These are random and sudden events that can leave deep long term markings which are especially visible from space imagery. The *Saraswati* project and similar project on Nile are two spectacular examples of this.

4.1.3 Magnetic field changes: The Earth's magnetic field, is not a simple dipole but a highly complex structure whose multiple North and South poles have been meandering (and also disappearing) over time scales of millions of years with some changes which are truly abrupt. When artefacts are made, or volcanic magma is cooled, or when river beds settle, iron and other magnetic material will

orient itself along the global magnetic field. Hence a careful excavation can allow determination of the local magnetic field conditions and by comparing this with the long term data of the Geomagnetic fields, sites can be dated back to millions of years.

4.1.4 Earth's Precession: The earth rotates on its own axis with a period of 24 hours and revolved around the Sun once in 365.24 days. The Earth's axis of rotation is inclined to the plane of revolution at an angle of 23.5^{o}. The axis of rotation points to the Pole Star. This is responsible for the seasons and the apparent north-south motion of the Sun in the sky over the year. However, while the inclination of the axis is fairly constant[2], it's pointing drifts with a period of 24,000 years. The result is that the Pole star changes with a period of a fraction of 24,000 years and, more importantly, the zodiacal sign in which the Sun will rise in a particular phase of the year also gradually shifts. Hence historical records of the drift of the zodiacal sign at equinox also changes over a period of a few thousand years. This is particularly useful in dating some of the ancient Indian literature. This also brings forward the month of Summer by 1 week every 500 years.

4.2 Sun: The Sun has obvious 24 hour periodicity due to the rotation of the earth. In addition, the Sun has a periodicity of 365.24 days as the Earth revolves round the Sun. Due to the inclination of the orbit, the duration of the day-time and night-time at any location changes over the year. In higher latitudes, the Sun can disappear for several days in winter and barely set in Summers and many civilisation have noted this effect. More importantly, the Sun drifts in the sky, and its noon time location noon changes significantly over the year and the fact that the Sun moves north or south on a particular day has also been noted and speculated upon in ancient literature. Also, with the precession of the earth (see point 4.1.4), this has been a very useful marker for dating older manuscripts.

The Sun also has an 11 year periodicity of activity in terms of the number of highly energetic particles it throws on the earth. These particles come and impinge on the Earth and produce a radio active isotope of carbon (C^{14}) which has a decay half life of about 5,600 years. Hence the ratio of C^{14} to normal carbon (C^{12}) reveals the age of organic matter which absorbs both forms of carbon without distinction. This has been used effectively and the technique is known as *Carbon dating*. However, this 11 year periodicity is not constant and different 11 year cycles have different intensities. To make matters even more interesting the Sun apparently has another 200 year periodicity in the 11 year cycle.

4.3 Moon: The moon has an obvious about 14.5 day periodicity from new moon (*amavasya*) to full moon (*purnima*). Half this period has been used to define the week and twice the period (29.5 days) has been used to define a month. However, the

[2] The inclination changes with various periodicities between 22^{o} to 25^{o} with a periodicity of ~ 98,000 years***

Moon itself has very little effect on the earth beyond causing tides[3,4]. The most important astronomical effect that the Moon produces is the Solar and Lunar Eclipses. While Lunar Eclipses can be seen over an entire hemisphere, Solar eclipses have very small path of motion on the Earth. Hence descriptions of Eclipses in the literature have been used for everything from the Great Epics to Shivaji's birthday. Another interesting use of this has been the checking of the calculations of tithis based on ancient Indian method of calculation to date the calculations themselves and to extend them for use over a much larger time period.

4.4 Planets: Five planets, Mercury, Venus, Mars, Jupiter and Saturn can be seen by unaided eyes. They go around the Sun with a period varying from few days to a few years. They therefore appear in different constellations over different extended periods. Each planet has its own characteristic importance and we discuss each of them separately. However, since all the planets rotate around the Sun in the same plane, to us, all the planets and the Sun remain in the same zodiacal region and do not deviate very far. Comets have no such compulsions[5].

4.4.1 Mercury: Mercury closest to the Sun, it revolves around the Sun once in about 88 days (0.24 years). The result of this is that Mercury appears very close to the Sun, not deviating by more than 23.6^{o} away from the Sun, appearing in the morning for about 40 days and in the evening for about 40 days. When it is too close to the Sun, it is invisible. It is therefore difficult to see and it took the emerging civilisations a lot of time before identifying as a single object. It also probably gave the first clues to the Heliocentric origin of the Solar System.

4.4.2 Venus: With a revolution period of 225 days (0.62 years), Venus can come quite close to the Earth with significant changes in its brightness over this period. Since it can be seen as far away as 46^{o} from the Sun, it a very distinct object in the sky and, like Mercury, can appear with rising or setting Sun and is known both at morning star and evening star in the literature. Also, since it can come close to the Earth, the sense that it has a colour different from conventional white of the stars is also very clear when one observes the planet.

4.4.3 Mars: It is the first of the outer planets. Mars takes 686 days (1.88 years) to revolve around the Sun. Since this is almost twice the period, while the Earth (Sun, as seen by us) moves through 1 zodiacal sign in 1 month, Mars stays in the same zodiacal sign an average for 2 months. Also, Mars exhibits the most spectacular retrograde motion in the sky, apparently moving in forward direction for most of the time and then reversing its direction for a few days, making a loop

[3] This is not strictly true. Moon gives the stability to the Earth's spin and without the Moon, Earth would have been a very erratic on the scale of thousands of years in its movements and this would have made intelligent life difficult on Earth.

[4] Lovers of astrology have often suggested that the Moon has a profound effect on the life on earth and have suggested, against all evidence that Moon controls our whole being. It is probably useful to point out that 5 kg stone 1 meter away from a person exerts a stronger force on a person than the Moon!

[5] In the discussion below, when we mention the revolution period in units of days, it is Earth days and the numbers are not related to the rotation period of the planet.

and then returning to its forward direction of motion again. This is an observational effect that occurs when Earth, moving in the inner track around the Sun, overtakes Mars on the outer track. All planets, in principle, show this retrograde motion but it becomes less marked for planets that are farther away and is invisible in inner planets due to the fact that when retrograde motion occurs, they are very close to the Sun and hence not observable. It is also interesting that their anti-Sun (dark) side faces the Earth during retrograde motion.

4.4.4 Jupiter: The king of planets and a very bright object, from observational astronomy perspective, Jupiter is clearly large enough to appear like a broad object and hence it does not twinkle. Also, its revolution period is almost 12 (11.88) years. Hence it stays in the same zodiacal sign for 1 year giving it a nice resonance in observation. It is also well observed and gets very quickly recognised. It has been called *Guru* in the Indian system and occupies the place of pride in all religious and astrological works.

4.4.5 Saturn: The last of the easily observable planets (Uranus *can* be seen but only rarely) it has a period of 29.5 years and hence it moves even more slowly in the night sky staying in the same constellation for 2.5 years. In a life time of observations, Saturn will not even complete 3 revolutions! Hence its movements have been noted and discussed of periodicities etc. indicate observations done over several generations.

4.5 Constellations: The sky is divided into various patterns whose boundaries and star associations are similar in most of the ancient civilisations, except for the imposed mythological interpretations are different for different civilisations. There are several ways in which constellations can be used in archaeo-astronomy.

4.5.1 The patterns and mythologies are associated with the way the dots are joined and the latitude from which they are observed. Hence these stories are *latitude* dependant and can be used effectively to determine the approximate latitude where the civilisation originated.

4.5.2 Since these are patterns of the star that are sufficiently far away from the Sun in the night sky, they have a periodicity of 12 months. By association, they get connected to the relative location of the Sun on earth and therefore seasons. Constellations have therefore been associated with seasons i.e. with solstices (when the Sun reverses its direction in the sky) and Equinoxes (when the Sun crosses the equator or is midway between solstices).

4.5.3 Due to precession of the Earth (see point 4.1.4) the Sun rises in different constellations at solstice over centuries and therefore the definitions of “summer and winter constellations” also change. Any recording of these therefore form important clues to dating of documents. Hence, drawing of constellations and their associated myths, and location of Moon and Sun during a specific period provide important markers to astro-sensitive documents.

4.5.4 The shapes of constellations are themselves not constants since the stars move in the galaxy. This movement, as seen from earth is small but can significantly deform constellations over thousands of years. So, detailed description of constellations is also very useful. Constellations can also change due to appearance of new stars or disappearance of existing stars and this also provides important information.

4.5.5 One more way in which constellations are important is for the entry and exit of planets through them. These are often associated with astrological omens and hence these events are well recorded.

4.6 Exploding Stars: Stars are not eternal. They shine by burning fuel to produce heat and light and hence they run out of fuel. While smaller stars simply die away, large stars have truly spectacular death when they can even be visible during day time. These transient stars (Supernovae) remain visible for about a fortnight. In the last two thousand years, as many as 7 major stellar explosions have occurred in different constellations which should all have been visible to unaided eyes. Deeper into the past even more events should have been recorded. Hence, any record of these explosions can date the document to an accuracy of a fortnight even thousands of years. When these explosions occur close to the earth (in astronomical terms) they also leave behind important radioactive signals such as C^{14} (see point 4.2) which have also been effectively used to date palaeontological samples.

4.7 Comets: Ancient Indian literature is replete with information on comet citing and even their classification. However, comets have not been explored as serious sources of knowledge for archaeology data since comets can be periodic or make only one or few journeys around the Sun before disappearing for ever. Hence any citing of comet cannot be uniquely associated to any time period and as such are not used for dating documents. However, due to their random appearance, they have been favourite tools of astrologers and hence are relatively well documented. An immense potential exists for evaluation of the description of comparison. Also, some comets are periodic and a converse search may also yield potentially useful information. Comets colliding with earth, their description and geological dating of the site of impact are also potentially useful tools of observation.

5. Methods of Using Archaeoastronomy

Clearly, given the ease of observation and apparent interest in astronomy in all the civilisations, detailed (if encrypted) recording of astronomical observations must exist for all periods of human civilisation. Hence, the various periodicities and time varying astronomical information discussed in section 4 can be used to date and study events in several different manners. We discuss some of the methods here.

5.1 **Interpretation of *shlokas*:** This is probably the simplest and the most commonly used method of Archaeoastronomy in India. *Shlokas* describing the rise of the Sun at

equinoxes etc. have been quoted in the literature to date some of the Vedic literature to dates far earlier than the conventional dates given by other means. This method seems obviously correct, in the sense that if there is a discussion of Sun rising in a specific constellation at Equinox, then the document mentioning it must be dated to that period. However, this method has often been criticized claiming that the entire *shloka* could have been added post-facto by someone with basic understanding of astronomy. Equally, rare astronomical events of finding planets where they should not be, have also been used to date documents but these have been criticised on the ground that the occurrence of the event was rare and the whole discussion of possibility of event was only speculative! Both criticisms are not very strong since, quite often, the mathematical and observational tools required to calculate astronomical event are extremely sophisticated, relying heavily on satellite based astronomy. Hence, many of the tools used to extracting information today, were not even available to the people who could, in theory, have contaminated ancient document to make them appear more ancient. Even so, the best counter argument against this criticism is to identify a large number of such events so that the argument that it was a lucky guess becomes inadmissible. In spite of this kind of criticism, well documented references to astronomical events are major pointers to the sophistication of authors and astronomical information.

5.2 Study of construction of architectural sites: Several major and minor monuments were made with detailed sensitivity to the location of the Sun, its path and also with consideration to the Moon. Stonehenge in UK, Pyramids in Egypt and our own Sun Temples are all classical example of ancient architecture showing great sensitivity to astronomy. Design and description of *Vedis* (altars) and other religious sites have all been shown to be sensitive to the presence or absence of a particular astronomical object in a particular location. All these can be effectively used to study these sites.

5.3 **Matching of *Kundalis*:** Quite often, at least for more recent periods, the nobles were very enthusiastic readers of astrological signs at their birth or the birth of other great ones. Some of these have survived and have been used to date the periods of these kings. Potentially this is probably the most direct method of dating events since a *kundali* requires detailed description of the location of several astronomical objects and can be easily checked for consistency as well as accuracy.

5.4 **Designs of constellations**: The design of constellations, the rise and setting of the Sun during a fixed period etc. can all now be calculated very accurately. Orion, for example is described more as a case of a warrior in the Greek and other northern hemisphere astronomies compared to Indian astronomy where the constellation has a more polite representation. This is largely because; this constellation appears overhead and hence flat over India while in further northern latitudes, it appear over the horizon, appearing vertical. Also, there are additional descriptions of constellations like *Prajapati* which includes stars that are so dispersed that it is impossible to make sense out of it in a direct manner. It is more than likely that the sky geometry or some stars no longer visible played an important role in the past. Similarly, the seven sisters of the Pleiades cluster has only six stars visible to unaided

eyes. This is because one star has now come either very close to the other or has simply died away.

5.5 Language, idioms, customs and *Adhika–Maas*: Language, especially customs are often dictated by astronomical considerations and daily life is full of these examples. But more interesting are the manner in which tithis are calculated and their formulation is done. A study of such methods of how a particular astronomical reference came in the language itself is very interesting. Names of weeks for example, reveal the relative importance given to various astronomical objects in terms of their motion in the sky. Similarly, the concept of *adhika–maas* (intercalary month), and the manner of its incorporation to synchronise the solar and lunar calendars was introduced quite early in calendars. The implementation of the *adhika–maas* itself is therefore a revelation on the period of activity and the manner of implementation also gives a good idea about the intellectual status of the system. For example, while most of these calculations were re-done during Aryabhatta's period, many other periods have seen blind adaptation of the method with ad hoc corrections which show a complete lack of understanding. Similarly, *Sharad Purnima* and *Uttarayan* no longer relate to the astronomical events they were related to originally and the differences are also very revealing.

5.6 **Astronomical speculations and mythologies:** Association of specific gods to specific days and planets with the implied importance associated to the astronomical objects and gods is one example of daily mythology giving useful information on the evolution of human thought. Equally importantly, there are mythologies of gods and of creation, the presence or absence of some animals in the constellations, the unanimity in their association across civilisations are all related to the astronomical and environmental sensitivity of the generations. Few abortive attempts have also been made by some kings to change astronomical associations and these also have important clues to the civilisations.

5.7 Relation with Geological changes. Geological changes are association with astronomy through superstition. The rarer an event the more obscure is the astronomical event to which it is associated[6]. But sudden calamities are associated with comets and other rare objects. Hence knowing that a civilisation suffered a specific calamity immediately and the astrological interpretation given to it, again reveal a lot about the civilisation. Similarly, sacrifices associated with specific events are also very important.

5.8 Re-calculations of old data: All civilisations have worked hard to predict astronomical events and create calendars. All these calculations, being phenomenological in origin were useful only for short periods before they began deviating from reality. How a particular astronomer or civilisation, used the mathematical tools at its disposal to determine various astronomical parameters, what

[6] For example, it is said that Orion is associated with flooding of Nile is associated with Orion since both are periodic and time-coincident, that is, Nile floods in the month when Sun sets in Orion, however this is controversial.

constants it used to derive a calculation and how they attempted to correct for deviations makes a fascinating story in its own right. More importantly, the values of various parameters and the mathematical formulation used are also important windows to the understanding of the civilisation.

6. Current status

Nothing I have said in here is new or unknown. The purpose of this article was to bring various ideas under a single title so that they can be looked at, in totality and can be used as interlinked clues rather than random, one off study.

Also, this seems to be the correct time to begin this study since several developments in the last 5 to 10 years have made astronomical extrapolations far more feasible and accurate. The field is now ready for take off since interplanetary mission have forced development of accurate ephemeris of planetary motions. These calculations now allow calculation of planets for more than 7,000 years into the past. New very accurate catalogues of location of stars and their movement in the sky have been made using dedicated satellites. These satellites have therefore given us an ability to calculate the exact sky patterns for 10,000 years. Together, these tools now allow us to plot the exact sky (except for comets) over extended periods of human civilisation. The field is especially well suited for *amateur* astronomers and people with basic sensitivity to astronomy – does NOT require training in professional astronomy or physics.

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