On the Antiquity of the Star Coordinates from Indian Jyotiṣa Śāstras

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I INTRODUCTION

A comparison is made between coordinates for 35 stars listed in traditional Indian astronomical texts (*jyotiṣa śāstras*) and the coordinates of corresponding stars listed in modern tables. I find that the error vectors pointing from the modern star positions to the corresponding *jyotiṣa* star positions are strongly correlated with the reversed proper motion vectors of the stars. Once precession is taken into account, the modern star positions show a tendency to move towards the *jyotiṣa* star positions as we go back in time.

To evaluate this, I first consider the null hypothesis, which says that we should not expect to find a significant relationship between errors in *jyotiṣa* star coordinates and proper motions of stars. I give statistical arguments showing that this hypothesis is not correct.

If there is a significant relationship between proper motions and *jyotiṣa* star coordinates, then the simplest explanation for this is that the *jyotiṣa* star coordinates were measured in the distant past. As time passed, the stars slowly moved from their positions and thereby generated error vectors pointing back along their paths. Given this hypothesis, it is possible to calculate the time of measurement of the *jyotiṣa* star coordinates. I find that these coordinates divide into a group 25,000–55,000 years old and a group less than 5,000 years old. There is also a group that cannot be clearly dated, and there is evidence suggesting that the stars in this group may not be correctly identified.

II JYOTIṢA STAR COORDINATES

Several *jyotiṣa śāstras,* such as the *Sūrya-siddhānta* and the *Brahmagupta-siddhānta*, contain lists of polar ecliptic latitudes and longitudes for stars (1). These stars include the *yogatārās* (or "principle stars") of the 28 *nakṣatras* or lunar mansions. The list in the *Sūrya-siddhānta* includes seven additional stars, making a total of 35. These are Agastya, Mṛgavyādha, Agni, Brahmahṛdaya, Prajāpati, Apāmvatsa, and Āpas (2). I will call all these stars "*jyotiṣa* stars" and refer to them by their Sanskrit names.

Given a *jyotiṣa* star, it is natural to try to identify which star it corresponds to in the nomenclature of modern Western astronomy. I shall call this the "modern star" corresponding to the given *jyotiṣa* star. The tenth-century Muslim scholar Alberuni was perhaps the first Westerner to seek such identifications (3). This effort was continued by scholars such as Colebrooke (4), Burgess (5), and Kay (6) in the nineteenth century and B. Dikshit (7) and David Pingree (8) in the twentieth.

I have adopted the set of identifications in Table 1 for the 35 *jyotiṣa* stars. These identifications are based on the discussion given by Burgess in his translation of the *Sūrya-siddhānta* (9). They are exactly as given by Burgess with the exception of two or three cases where he did not give a clear choice. In those cases I made an arbitrary choice from the alternatives which he offered.

We can compare a given *jyotiṣa* star position with the corresponding modern star position in the following way: First convert the polar ecliptic latitude and longitude of the *jyotiṣa* star into right ascension and declination (10). This gives the position of the star in modern coordinates at its particular epoch. Then apply formulas for precession to obtain the right ascension and declination of the star in the epoch A.D. 2000 (11). These coordinates define the "*jyotiṣa* star position" in modern form. They can be compared with the right ascension and declination of the corresponding modern star listed in a catalogue for the epoch A.D. 2000 (12). These latter coordinates define the "modern star position."

A great circle arc can be drawn between the star's modern position and its *jyotiṣa* position. Let D be the length of this arc in degrees. The "error vector" is a vector of length D starting at the modern position and pointing along this arc. According to Burgess, the epoch of the *jyotiṣa* star coordinates is about A.D. 490 (13). The argument for this is that if we precess the *jyotiṣa* star coordinates from various epochs to A.D. 2000, we find that the average of the lengths of the error vectors pointing from the modern star positions to the corresponding *jyotiṣa* star positions are nearly minimal for the epoch A.D. 490. Therefore I have used this epoch when converting *jyotiṣa* star coordinates to the epoch of A.D. 2000.

III PROPER MOTIONS OF STARS

Many stars are observed to move slowly with respect to the celestial sphere. These motions, called proper motions, vary from star to star. For a typical star, the proper motion amounts to a small fraction of a second of arc per year, and it is directed along a great circle arc on the celestial sphere.

In the star catalogue *Sky Catalogue 2000.0* (for the epoch A.D. 2000), the present rate of proper motion in both right ascension and declination is listed for each star. The negatives of these two quantities, expressed in degrees per 10,000 years, define a vector which describes the motion of the star on the celestial sphere as we follow it back in time. I will use the term "reversed proper motion vector" to refer to this vector. (For some stars the distance from the earth and the radial velocity are also listed. These quantities can be used to compute an acceleration or deceleration of the proper motion along the celestial sphere.)

I should emphasize that the right ascension and declination of a star are meaningful only in reference to a particular epoch. This is due to the gradual shifting of these coordinates caused by the precession of the equinoxes. In general, whenever I refer to a star's position, I am referring to its right ascension and declination for the epoch A.D. 2000. This provides a standard way of specifying the position of a star on the celestial sphere. The movement of a star over thousands of years due to proper motion is also expressed in terms of right ascension and declination for A.D. 2000.

Let us suppose, for the sake of argument, that the position of a star was measured long ago with a certain error, and the results of this measurement were passed down to the present as the *jyotiṣa* coordinates for the star. As time went by, the position of the star changed as a result of the star's proper motion. Thus the error vector pointing from the modern star position to the *jyotiṣa* position must consist of two components: one due to proper motion and the other due to inevitable errors in measurement. If the error in measurement is small compared with the shift due to proper motion, then we would expect the modern star position to move towards the *jyotiṣa* position as we follow its movement backward in time.

As we track its motion backwards in time, the star follows a great circle arc that begins at the modern position and extends in the direction of the reversed proper motion vector. Another great circle arc can be drawn between the star's modern position and the *jyotiṣa* position. We shall call the angle A between these two arcs the "angle of approach." This angle lies between 0 and 180 degrees. It is the angle between the reversed proper motion vector and the error vector, as defined above.

As we follow the star's position backward in time, there comes a time when the distance between this position and the *jyotiṣa* position is minimal. Define T to be this time in years before A.D. 2000 and D_{min} to be the minimum distance in degrees. D_{min} can be compared with D, the length of the error vector pointing from the modern star position to the *jyotiṣa* star position. If the angle of approach A is greater than 90 degrees, then the star's position moves further away from the *jyotiṣa* position as we go back in time. In this case, T will be 0 and $D_{min} = D$.

The average value of D is 3.09 degrees for the 35 stars listed in the *Sūrya-siddhānta*, using the star identifications of Burgess. The *Brahmagupta-siddhānta* gives a list of coordinates for the 28 *yogatārās* of the *nakṣatras* (14). On the whole, these coordinates seem to be more accurate than the coordinates for the 28 *nakṣatras* in the *Sūrya-siddhānta* list. We have therefore created a composite list of star coordinates by adding the seven additional stars found in the *Sūrya-siddhānta* to the *Brahmagupta-siddhānta* list. For this composite list the average value of D is 2.78 degrees. I will use this list of *jyotiṣa* star coordinates in the calculations discussed below.

Figure 1 gives an example of a modern star that moves towards its corresonding *jyotiṣa* star position as we go back in time. The modern star is Capella (Alpha Aurigae), and its present position is marked by the circle labeled "Capella." The position of Capella at successive 10,000 year intervals going into the past is maked by a series of small circles. These approach the large double circle marking the *jyotiṣa* position of Brahmahṛdaya at approximately 50,000 years ago.

IV THREE HYPOTHESES

The following three hypotheses can be offered regarding possible relationships between *jyotiṣa* star coordinates and proper motions of stars:

1. Null hypothesis. There is no systematic relationship between the proper motions of stars and the error vectors pointing from modern star positions to corresponding *jyotiṣa* star positions. We therefore expect angles of approach from modern star positions to *jyotiṣa* star positions to be more or less random.

2. Historical hypothesis. The *jyotiṣa* star positions were measured in the remote past, and these stars have moved considerably since that time due to proper motions. Therefore, angles of approach tend to be smaller than they should be on the basis of chance expectation. We can learn about the time of measurement of the *jyotiṣa* star positions by computing the times T defined above.

3. Unknown alternative. There is a systematic relationship between the proper motion vectors of stars (going backwards in time) and the error vectors pointing from modern star positions to corresponding *jyotiṣa* star positions. However, the historical interpretation is incorrect, and some other explanation is required to account for this relationship.

V THE NULL HYPOTHESIS

At first glance, one would expect the null hypothesis to be correct. After all, proper motions of stars are very small, and they were measured only recently using powerful modern telescopes. They should have nothing to do with errors in naked-eye measurements made many centuries ago. However, it turns out that the null hypothesis can be ruled out by a statistical study of the data. I will begin by giving this statistical analysis.

First, one might suppose that error vectors based on *jyotiṣa* star coordinates should point in random directions relative to reversed proper motion vectors. This suggests that the angles of approach A_i (for stars i=1 to 35) should be uniformly distributed between 0 and 180 degrees. The theoretical mean for one angle selected according to the uniform probability distribution on [0,180] is $\mu = 90$ degrees, and the theoretical standard deviation is $\sigma = 180/12^{1/2} = 51.96$ degrees. The theoretical mean and variance for an average of 35 angles selected independently according to this distribution are $\mu' = 90$ and $\sigma' = \sigma/35^{1/2} = 8.78$ degrees, respectively.

If we compute the angles of approach using the star coordinates and star identifications given above, we find an average A_i of 55.78 degrees. This is about 3.9 standard deviations below $\mu' = 90$ degrees.

This finding seems to be contrary to what we might expect from the null hypothesis. However, the directions of the 35 reversed proper motion vectors are distributed nonuniformly, with a bias towards the north. Likewise, the directions of the 35 error vectors are also distributed nonuniformly. Could it be that these nonuniform distributions are responsible for the unexpectedly small angles of approach?

To answer this, it is necessary to take a deeper look at the statistics of the angles of approach. One way to do this is to assign to each star the proper motions of each of the 35 stars. This results in 35×35 = 1225 artificial "stars" which can be used to compute angles of approach. These 1225 combinations have the following properties:

(1) They have the same distributions of error vectors and reversed proper motion vectors as the 35 real stars.

(2) In the 35×35 combinations, each error vector is associated once with each proper motion vector. This erases any particular relationship between error vectors and proper motion vectors that may have existed in the original set of 35 stars.

So if the nonuniform distributions of error and reversed proper motion vectors are responsible for the small angles of approach, then we would also expect the 1225 combinations to yield small angles of approach on the average. The mean angle of approach for the 1225 artificial combinations is $\mu = 82.06$ degrees, and its standard deviation is $\sigma = 50.92$ degrees. This mean is still quite a bit higher than the average of 55.78 degrees that we found for the 35 real stars.

Given the distribution of angles created by the 1225 combinations, how probable is it that the average angle of approach will be as low as 55.78 degrees? The theoretical standard deviation for the average of 35 angles of approach chosen independently according to this distribution is $\sigma' = 50.92/35^{1/2} = 8.61$. Thus 55.78 degrees is 3.05 standard deviations below the mean of $\mu'=82.06$ degrees. This is smaller than 3.9 standard deviations, but it is still a statistically significant deviation from the mean.

Additional evidence against the null hypothesis can be obtained by looking at certain weighted averages of the angles of approach. It turns out that if we use certain weights based on historical studies of the *nakṣatras*, we find that the statistical significance of the correlation between reversed proper motion vectors and error vectors becomes greater. I will explain this after first introducing the idea of a weighted average. A weighted average is given by the following formula:

$$\alpha = \sum_{i=1}^{N} W_i A_i \; / \; \sum_{i=1}^{N} W_i \qquad [1]$$

where the W_i's are nonnegative weights.

One set of weights measures the degree of certainty of scholars in the identification of modern stars corresponding to the *yogatārās* of the 28 *nakṣatras*. Six different scholars have given from 1 to 4 different choices for these 28 *yogatārās* (15). The number Alt_i of choices for *yogatārā* i can be interpreted as a measure of the uncertainty of scholars regarding the identity of the *yogatārā*. Thus 4-Alt_i can be seen as a measure of the scholars' degree of certainty. The average computed using W_i = 4-Alt_i tends to emphasize those *nakṣatras* for which scholars are in agreement on the identification of the *yogatārā*.

Another set of weights represents the degree of success of Alberuni in his attempt to identify the *yogatārās* (16). These weights, called Alb_i, are defined as follows: Alb_i = 2 if Alberuni felt he was successful in identifying the *yogatārā* i; Alb_i = 1 in the one case where he seemed to make an ambiguous statement; and Alb_i = 0 if Alberuni said he could not identify *yogatārā* i.

A third set of weights, called $Sieu_i$, has to do with correspondences between the Chinese lunar mansions called *sieus* and the *yogatārās* of the *nakṣatras*. Each Chinese *sieu* is a single star. $Sieu_i$ = 0 for *nakṣatra* i if Burgess concluded that the corresponding *sieu* does not lie in the *nakṣatra* constellation (which may consist of several stars); $Sieu_i$ = 1 if the *sieu* might be in the constellation; $Sieu_i$ = 2 if it is in the constellation but is not the *yogatārā*; and $Sieu_i$ = 3 if it is the *yogatārā*. The three sets of weights 4-Alt_i, Alb_i, and $Sieu_i$, are listed in Table 2.

Table 3 lists the results of calculating average angles of approach using these weights. In line 1 of the table, all 35 stars were used and the weights were W_i=1. In this case α is simply the average of the angles of approach for the 35 stars, and the results are as reported above.

In line 2, the average was restricted to the 28 *nakṣatras* and W_i=1. For this line, all the calculations are as before, except that 28 stars were used instead of 35. These calculations made use of the set of 28×28 = 784 artificial star combinations created by combining error vectors and proper motion vectors for the 28 *nakṣatras*. In this case the average angle of approach for the 28 *nakṣatras* turns out to be 2.17 standard deviations below the mean calculated for the 28×28 artificial combinations. (This lower value is partly due to the fact that we are using a smaller sample size.)

What happens when we look at more general weighted averages of the A_i's? If 28 A_i's are chosen independently from a distribution with mean μ and standard deviation σ, then the mean of the α given in equation (1) is simply μ' = μ. The standard deviation of this α is

$$\sigma' = \sigma \times [\sum_{i=1}^{N} W_i^2]^{1/2} \; / \; [\sum_{i=1}^{N} W_i] \qquad [2]$$

This reduces to the familiar formula $\sigma' = \sigma/N^{1/2}$ in the case where W_i=1. Here N=28.

Using this formula, we can compute the number of standard deviations separating the weighted average of the angles of approach and the mean calculated for the 28×28 artificial combinations. We find that for the weights W_i = 4-Alt_i and Alb_i, the statistical significance of the deviation from the mean is greater than in the case where W_i=1. In place of 2.17 standard deviations, we get 2.52 and 2.41, respectively.

This means that by emphasizing *nakṣatras* for which scholars were confident of their identification of the *yogatārā*, we obtain a more significant correlation between reversed proper motion vectors and vectors indicating errors in *jyotiṣa* star coordinates. Likewise, the correlation is more significant when we give emphasis to stars that Alberuni felt he could identify. A natural interpretation of this is that with these weights we are excluding (or de-emphasizing) *nakṣatras* which may have been falsely identified. By the null hypothesis, the angles of approach for falsely identified stars should not be significantly different from these for correctly identified stars (since all angles of approach should be more or less random). But this is not what we find.

Using the weights $Sieu_i$, we find that the weighted average is 2.56 standard deviations below the mean. In this case it turns out that we acquire a more significant correlation between error vectors and proper motions when we look at *nakṣatras* that are thought to correspond to Chinese *sieus*. As with 4-Alt_i and Alb_i, this set of weights may tend to select stars that are more securely identified. By the null hypothesis, these *nakṣatras* should not tend to have lower angles of approach than other *nakṣatras*, but it appears that they do.

VI THE HISTORICAL HYPOTHESIS

Since the null hypothesis does not hold up, let turn to the historical hypothesis. If this hypothesis is correct, then the times of closest approach for stars with small angles of approach should be estimates of how long ago the *jyotiṣa* coordinates of these stars were measured. The following string of numbers is a histogram of the times of closest approach for those stars out of the 35 that have angles of approach less than 45 degrees:

4 1 0 2 2 4 0 0 0 1 1 0 0 0 1

The first number gives the number of stars with times between 0 and 5,000 years ago. The remaining numbers give the numbers of stars with times falling in successive intervals of 10,000 years. We can see that there is one peak corresponding to the interval between 0 and 5,000 years ago and another peak corresponding to the broad interval between 25,000 to 55,000 years ago.

For the moment, let us disregard the extremely large ages represented by these peaks and try to evaluate their statistical significance. It turns out that it is easiest to do this if we restrict our attention to the 28 *nakṣatras*. For these stars, the histogram is:

4 1 0 2 1 3 0 0 0 0 0 0 0 0 0

We can create a weighted histogram using weights W_i by letting each number in the histogram be the sum of the W_i's for the stars falling in that number's time interval. If we do this for $W_i = \text{Sieu}_i$, we get:

0 0 0 5 3 6 0 0 0 0 0 0 0 0 0

It turns out that the five stars making up the more recent peak all have $\text{Sieu}_i = 0$ (meaning that none are Chinese *sieus*), and thus this peak does not appear in the weighted histogram. These stars are Punarvasu (Beta Geminorum), Maghā (Alpha Leonis), Svātī (Alpha Bootis), Abhijit (Alpha Lyrae), and Śravaṇa (Alpha Aquilae). They are all prominent stars with high proper motions, and they all fall in the set of nine *nakṣatras* with magnitudes less than 1.5. Note that the probability that five randomly chosen *nakṣatras* will fall in this group of nine is less than $(9/28)^5$. (In fact, it is 1/780.)

Given the null hypothesis, this histogram peak made of prominent stars must simply be a product of chance. However, the historical hypothesis provides a simple explanation for it. We can argue that since these stars are fast moving and prominent to the eye, their positions must have been measured relatively recently. Otherwise, they would have moved so far from their recorded positions that those positions would have been obviously in error. Burgess argues that the observed correspondences between *nakṣatras* and *sieus* must be due to cultural contact between Indian and Chinese astronomers. We can hypothesize that the stars in the recent peak do not correspond to *sieus* because they were added to the *nakṣatra* system after this period of close cultural contact. Although this explanation is certainly speculative, it does provide possible reasons for a pattern which, according to the null hypothesis, must be entirely due to chance.

Now let us consider the histogram peak in the interval from 25,000–55,000 years ago. This peak is a concentration of ages around a central point of 40,000 years. The question is: Is this concentration of ages statistically significant, or is it just a product of chance?

We can answer this question by taking advantage of the fact that Sieu_i cancels the recent peak in the histogram and leaves the 25,000–55,000 year peak. This gives us a criterion for singling out the older peak which is independent of our findings regarding proper motions and error vectors. (It is independent because Sieu_i depends only on Burgess's study.) Let $D4_i$ be the distance in degrees between the ith *jyotiṣa* star position and the position occupied by the corresponding modern star 40,000 years ago. If the 25,000–55,000 year peak is significant, then the weighted average of the $D4_i$'s using $W_i = \text{Sieu}_i$ should be unexpectedly small.

This turns out to be true. The weighted average of the $D4_i$'s using Sieu_i as weights is 1.47 standard deviations below the mean for this average calculated using the 784 artificial stars. If we use the weights $\text{Sieu}_i \times \text{Alb}_i$ which reflect both the correspondence with Chinese *sieus* and Alberuni's star identifications, the corresponding figure becomes 1.7 standard deviations. Thus we can conclude that the 25,000–55,000 year peak has some statistical significance, but it is not highly significant.

However, there is additional evidence suggesting that this peak should be taken seriously. If we observe the individual diagrams showing the relation between modern star positions and *jyotiṣa* position, we can find several instances in which the *yogatārā* identified by Burgess does not closely approach the *jyotiṣa* position as we go back in time over an 80,000 year period. However, in some of these instances there is another star in the *nakṣatra* constellation that does closely approach the *jyotiṣa* position in this time period. Table 4 lists these new star identifications for Bharaṇī, Mṛgaśīrṣa, Puṣya, Pūrvaphalgunī, and Mūla.

If we adopt these five new *yogatārā* identifications, what effect does this have on the histogram of ages? Does it tend to disperse the two age peaks that we have already noticed, or does it accentuate them? The age histograms for all 35 stars and for the 28 *nakṣatras* become:

4 1 0 2 2 6 1 1 0 1 1 0 0 0 1

4 1 0 2 1 5 1 1 0 0 0 0 0 0 0

If we compare these with the corresponding histograms for the pure Burgess star identifications, we find that the two age peaks remain, and that the number of stars in the 45,000–55,000 year range has become greater. With these modified star identifications, we can again calculate the weighted average of the $D4_i$'s using the $Sieu_i$'s as weights. This weighted average is now 2.0 standard deviations below the mean based on the 784 artificial stars. If we use the $Sieu_i \times Alb_i$'s as weights, this figure becomes 2.3 standard deviations.

These results indicate that the 25,000–55,000 year peak has become more prominent as a result of the new star identifications. These identifications were made on the basis that the chosen star should closely approach the *jyotiṣa* star position as one goes back in time. They were not specifically chosen so that it would approach the *jyotiṣa* position in the interval of 25,000–55,000 years ago. Yet the ages of closest approach for the five new identifications are 40.7, 53.5, 73.9, 64.4, and 48.2 thousand years, respectively. Thus they do fall on the high side of this peak.

Figure 2 illustrates the choice of the new star identification in the case of Mūla. Burgess identifies the *yogatārā* of this *nakṣatra* as Lambda Scorpionis, but several other authorities disagree. We can see from the figure that Lambda Scorpionis barely moves over a 50,000 year period. However, Epsilon Scorpionis moves almost directly towards the *jyotiṣa* position of Mūla as we go back in time. Thus by visual inspection, it is a natural replacement for Lambda.

VII SUMMARY DISCUSSION OF THE THREE HYPOTHESES

According to the historical hypothesis, the 25,000–55,000 year peak represents a period of astronomical measurement that took place roughly 25,000–55,000 years ago. Of course, the obvious objection to this is that at this time civilization didn't exist. Astronomy and the transmission of astronomical knowledge from generation to generation are thought to be impossible in this period.

It is generally accepted that humans beings of modern type have existed for at least 40,000 years. But agriculture and settled village life are thought to have arisen only 7,000–10,000 years ago (17). Early *Homo sapiens sapiens* presumably had the same talents and capabilities as modern humans, and one wonders why they waited 30,000–33,000 thousand years before starting the explosive development of civilized life. Could it be that civilization arose more gradually over a longer period of time?

Many ancient peoples apparently thought so. For example, fragments of the writings of Manetho, an Egyptian historian dated to the 3rd century B.C., give a period of some 30,000 years to early Egyptian civilization (18). Berossus, a Babylonian historian of the same period, assigned 432,000 years to early Babylonian history (19), and a similar time span is found in the king lists of Sumeria (20). The period of 432,000 years is, of course, reminiscent of the Indian yuga cycles, even though these are regarded by some indologists as a recent invention by astronomers (21).

It is easy to dismiss these traditions as sheer mythology, but it is possible that they may contain some truth. Perhaps sophisticated arts and sciences go back further than is generally believed.

Nonetheless, we may chose to reject the historical hypothesis. If we also reject the null hypothesis, then we are left with hypothesis three: There is a significant relationship between proper motions of stars and errors in *jyotiṣa* star positions, but this has nothing to do with the slow drift of stars after an ancient period of astronomical measurement. Unfortunately, since proper motions of stars are exceedingly slow, it is hard to see how their effects could become manifest over short periods of time to pre-telescopic astronomers. Long periods of time would seem to be necessary, and this suggests that some form of historical explanation is required.

I will therefore close by summing up the evidence presented in this paper that goes against the null hypothesis. This evidence can be summed up as follows:

1. The data for the 35 pairs of modern and *jyotiṣa* stars can be used to create an artificial distribution which has the same distributions of proper motions and error vectors as the 35 pairs, but eliminates all correlations between proper motions and error vectors. The null hypothesis predicts that the average angle of approach α for the 35 stars should be about the same as the average angle of approach μ for this artificial distribution. But actually α is significantly lower than μ, as the historical hypothesis predicts. This also holds true if we restrict our analysis to the 28 *nakṣatras*.

2. We can formulate three sets of weighting factors based on historical studies of the *nakṣatras* having nothing to do with proper motions of stars. These weights have to do with Chinese *sieus*, the *nakṣatra* identifications of Alberuni, and *nakṣatra* identifications by a number of other scholars. When the average angle of approach α is calculated using these weights, it becomes lower and its statistical significance increases. According to the null hypothesis, this should not happen, but it can be readily explained in terms of the historical hypothesis.

3. The histogram of age estimates shows two pronounced peaks. The recent peak, corresponding to the period between 0 and 5,000 years ago, is made up of bright, prominent stars, and none of these stars correspond to Chinese *sieus*. According to the null hypothesis, it is quite improbable for this to happen. However, it is amenable to a simple historical explanation.

4. We can evaluate the statistical significance of the older histogram peak by looking at distances $D4_i$ of modern stars from *jyotiṣa* star positions 40,000 years ago, at a time corresponding to the middle of this peak. If we use the weights $Sieu_i$, which eliminate the recent peak, we find that these distances are significantly lower than would be expected by the null hypothesis. The level of significance is 1.5 standard deviations using $Sieu_i$ and 1.7 standard deviations using $Sieu_i \times Alb_i$.

5. If we visually examine graphs of star movement for the 28 *nakṣatras*, we can find five cases where the *yogatārā* chosen by Burgess does not move towards the *jyotiṣa* star position as we go back in time, but there is another star in the *nakṣatra* constellation which does this. All of the results reported in points 1–4 were based on Burgess's star identifications. If we substitute the five new star identifications, we would naturally expect the average angles of approach to become smaller. This is because the new identifications were chosen with this in mind. However, we wouldn't necessarily expect the age estimates for these new identifications to reinforce the 25,000–55,000 year peak. There are not enough stars in the *nakṣatra* constellations to give us the opportunity to deliberately make such identifications. Nonetheless, the five new identifications all fall close to the 25,000–55,000 year peak (and shift its center a bit closer to 55,000 years). This is also unexpected, given the null hypothesis.

These five points add up to a strong case against the null hypothesis, and they give some direct support to the historical hypothesis. I would suggest that it might therefore be worthwhile to seek further evidence of high cultural achievements in time periods going back tens of thousands of years.

FIGURES

FIGURE 1

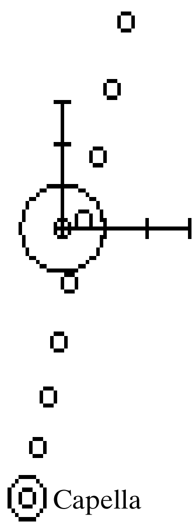

Figure 1. The large circle marks the *jyotiṣa* position of Brahmahṛdaya (see line 32 of Table 1). Burgess identifies this star as Capella (Alpha Aurigae).

The figure shows that Capella was very close to the position of Brahmahṛdaya about 50,000 years ago. Its distance will be 6.487 degrees in A.D. 2000, and it reached a minimum value of 0.453 degress in 48,164 B.E. (B.E. means before the epoch of A.D. 2000.)

FIGURE 2

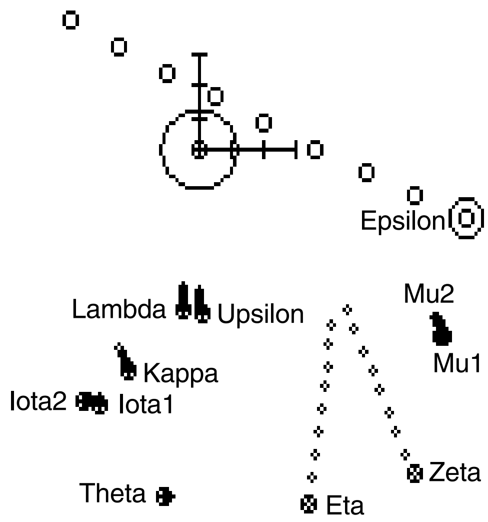

Figure 2. The large circle marks the *jyotiṣa* position of Mūla (see line 19 of Table 1). Colebrooke and Burgess agree that this *nakṣatra* should consist of the stars Upsilon Lambda Kappa Iota Theta Eta Zeta Mu Epsilon Scorpionis that form the tail of the scorpion.

The *Sūrya-siddhānta* says that the *yogatārā* is the eastern star of the group, and this is Iota. However, Colebrooke selects Upsilon and Burgress selects Lambda. This is done on the basis of position and agreement with the Arabic manzil ash-Shaulan, which consists of Upsilon and Lambda.

It turns out that Upsilon and Lambda barely move over a 50,000 year period. However, the figure shows that the star Epsilon reached a minimum distance of 1.667 degrees from the position of Mūla in 48,223 B.E. Therefore I have chosen Epsilon in Table 4 as a replacement for Burgess's choice of Lambda.

TABLES

TABLE 1

No.	Jyotiṣa star	Modern star	D	D_{min}	D4/D	A
1	Aśvinī	Beta Arietis	1.27	.58	.59	27.12
2	Bharaṇī	35 Arietis	1.29	1.08	.95	57.13
3	Kṛttikā	Eta Tauri	.61	.09	.19	8.75
4	Rohiṇī	Alpha Tauri	1.65	.24	.53	8.52
5	Mṛgaśīrṣa	Lambda Orionis	4.40	2.87	.99	40.76
6	Ārdrā	Alpha Orionis	6.26	6.25	1.00	86.84
7	Punarvasu	Beta Geminorum	.69	.31	9.33	26.55
8	Puṣya	Delta Cancri	1.75	1.58	1.41	64.76
9	Āśleṣā	Epsilon Hydrae	5.23	5.21	1.06	85.34
10	Maghā	Alpha Leonis	.21	.15	12.32	43.31
11	Pūrvaphalgunī	Delta Leonis	3.77	3.77	1.51	151.18
12	Uttaraphalgunī	Beta Leonis	.41	.41	14.62	145.01
13	Hasta	Delta Corvi	2.84	.49	.17	9.89
14	Citrā	Alpha Virgini	.94	.58	.64	38.09
15	Svātī	Alpha Bootis	2.85	.43	7.25	8.64
16	Viśakhā	24 Iota Librae	2.59	2.23	.90	59.60
17	Anurādhā	Delta Scorpii	3.05	3.03	.99	82.29
18	Jyeṣṭhā	Alpha Scorpii	1.50	1.20	.90	53.07
19	Mūla	Lambda Scorpii	5.02	.33	.94	3.83
20	Pūrvaṣāḍhā	Delta Sagittari	1.25	1.25	1.22	111.21
21	Uttaraṣāḍhā	Sigma Sagittari	2.31	2.31	1.23	146.56
22	Abhijit	Alpha Lyri	1.68	.99	1.46	36.02
23	Śravaṇa	Alpha Aquilae	.71	.38	7.72	32.23

No.	Jyotiṣa star	Modern star	D	D_{min}	D4/D	A
24	Dhaniṣṭhā	Beta Delphini	3.20	2.96	.92	67.58
25	Śatabhiṣaj	Lambda Aquarii	.67	.43	.65	40.10
26	Pūrvabhādrapadā	Alpha Pegasi	3.46	3.21	.94	68.34
27	Uttarabhādrapadā	Alpha Andromedo	5.78	5.78	1.09	92.21
28	Revatī	Zeta Piscium	1.18	1.18	2.15	124.16
29	Agastya	Alpha Carinae	.85	.11	.55	7.45
30	Mṛgavyādha	Alpha Can. Maj.	1.12	.99	11.13	62.61
31	Agni	Beta Tauri	7.92	7.12	.92	63.97
32	Brahmahṛdaya	Alpha Aurigae	6.49	.45	.20	4.01
33	Prajāpati	Delta Aurigae	6.57	2.50	.77	22.40
34	Apāmvatsa	Theta Virginis	1.84	1.16	.79	39.02
35	Āpas	Delta Virginis	5.91	3.29	.56	33.83

Table 1. Identification of modern stars corresponding to stars listed in the *Sūrya-siddhānta.* These identifications were given by Burgess. The quantities D, D_{min}, D4/D, and A were calculated for this set of identifications. These quantities are defined in the text.

TABLE 2

Nakṣatra	Modern star	4-Alt	Alb	Sieu	Sieu×Alb
Aśvinī	Beta Arietis	2	2	3	6
Bharaṇī	35 Arietis	1	1	3	3
Kṛttikā	Eta Tauri	3	2	3	6
Rohiṇī	Alpha Tauri	3	2	2	4
Mṛgaśīrṣa	Lambda Orionis	2	2	3	6
Ārdrā	Alpha Orionis	1	0	0	0
Punarvasu	Beta Geminorum	3	2	0	0
Puṣya	Delta Cancri	3	2	3	6
Āśleṣā	Epsilon Hydrae	0	0	2	0
Maghā	Alpha Leonis	3	2	0	0
Pūrvaphalgunī	Delta Leonis	2	2	0	0
Uttaraphalgunī	Beta Leonis	3	2	0	0
Hasta	Delta Corvi	2	2	3	6
Citrā	Alpha Virgini	3	2	3	6
Svātī	Alpha Bootis	3	2	0	0
Viśakhā	24 Iota Librae	1	0	2	0
Anurādhā	Delta Scorpii	2	2	2	4
Jyeṣṭhā	Alpha Scorpii	3	2	2	4
Mūla	Lambda Scorpii	0	2	2	4
Pūrvaṣāḍhā	Delta Sagittari	2	2	1	2
Uttaraṣāḍhā	Sigma Sagittari	0	2	1	2
Abhijit	Alpha Lyri	3	2	0	0
Śravaṇa	Alpha Aquilae	3	2	0	0
Dhaniṣṭhā	Beta Delphini	2	0	0	0
Śatabhiṣaj	Lambda Aquarii	3	0	0	0
Pūrvabhādrapadā	Alpha Pegasi	3	0	3	0
Uttarabhādrapadā	Alpha Andromedo	2	0	2	0
Revatī	Zeta Piscium	2	0	0	0

Table 2. Weighting factors. These weights represent the degree of certainty of scholars in the identification of the *yogatārās* of the 28 *nakṣatras* (4-Alt and Alb) and the degree of correspondance between Chinese lunar mansions and *nakṣatras* (Sieu). The weight Sieu×Alb is simply the product of the weights Sieu and Alb.

TABLE 3

	Weights	α	Mean	S.D.	No. of S.D.s
1	35 Ones	55.78	82.06	8.61	-3.05
2	28 Ones	61.40	82.43	9.67	-2.17
3	4-Alt_i	55.61	82.43	10.65	-2.52
4	Alb_i	54.69	82.43	11.51	-2.41
5	$Sieu_i$	49.30	82.43	12.92	-2.56
6	$Sieu_i \times Alb_i$	40.92	82.43	14.95	-2.78

Table 3. Weighted averages of the angles of approach. Here α is the weighted average of the A_i's using the indicated weights. In line 1 the average is for 35 stars with unit weights. In the remaining lines the average is limited to the 28 *nakṣatras*. The theoretical mean and standard deviation for 35×35 or 28×28 artificial stars are listed along with the number of standard deviations between α and the mean.

TABLE 4

No.	Jyotiṣa star	Modern star	D	D_{min}	D4/D	A
2	Bharaṇī	41 Arietis	2.69	2.25	.84	56.67
5	Mṛgaśīrṣa	Phi2 Orionis	5.16	.82	.31	9.20
8	Puṣya	Theta Cancri	1.82	.50	.53	16.05
11	Pūrvaphalgunī	Theta Leonis	1.88	.02	.38	.54
19	Mūla	Epsilon Scorpii	8.82	1.67	.25	10.93

Table 4. These star identifications are replacements for the corresponding identifications of Burgess in Table 1. Each replacement star belongs to the same *nakṣatra* constellation as Burgess's *yogatārā,* but it shows a stronger tendency to approach the *jyotiṣa* position as we go back in time.

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6. Kay, G.R., *Hindu Astronomy*, Cosmo Pub. (New Delhi), 1981, p. 118.
7. Dikshit, p. 345.
8. Pingree, D. and Morrissey, P., "On the Identification of the Yogataras of the Indian Naksatras," *Jour. of the History of Astronomy*, vol. 20, 1989, pp. 99–119.
9. Burgess, ibid.
10. I used the following equations to convert polar longitude and latitude (λ,β) into right ascension and declination (α,δ):

   $$\alpha = \arctan[\cos(\varepsilon)\sin(\lambda),\cos(\lambda)]$$
   $$\delta = \arcsin[\sin(\varepsilon)\sin(\lambda)] + \beta$$

   Here arctan[x,y] is the computer arctangent function, which automatically gives an angle lying in the proper quadrant.

   The quantity ε is the obliquity of the ecliptic. Its current value is about 23.5 degrees. However, I used 24 degrees, since this is the value used in ancient Indian astronomy, and it is the value that would have been used in India to transform star coordinates *into* polar longitudes and latitudes.

11. For calculations of precession of the equinoxes, I used the standard equations from Green, Robin M., *Spherical Astronomy*, Cambridge Univ. Press (Cambridge), 1985, p. 219 for the epoch of A.D. 2000.
12. I used Hirshfeld, A. and Sinnott, R.W., *Sky Catalogue 2000.0*, Vol. 1, Cambridge Univ. Press (Cambridge), 1982, for all modern star positions and proper motions.
13. Burgess, p. 244.
14. Dikshit, pp. 338–39.
15. Dikshit, p. 345.
16. Sachau, pp. 84–85.
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On the Antiquity of the Star Coordinates from Indian Jyotiṣa Śāstras Supplement

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This supplement presents diagrams showing star movements for the 35 cases considered in the paper "On the Antiquity of the Star Coordinates from Indian Jyotiṣa Śāstras." In that paper the tendency of the modern star to appoached the *jyotiṣa* star position as we move back in time was evaluated statistically. This supplement enables the interested reader to examine these star movements on a case by case basis.

In each diagream the *jyotiṣa* star position is indicated by the origin of a coordinate system surrounded by a large circle. The coordinate axes point west and north (from the point of view of an observer at the center of the celestial sphere), and they are marked in degrees. Modern star positions are indicated by sequences of dots. For each star, the large dot indicates the star position in A.D. 2000 and the successive dots indicate intervals of 10,000 years, going into the past. Eight such intervals are indicated for each star. For the 28 *nakṣatras* (which are listed first) the dots for the *yogatārā,* as identified by Burgess, are larger than the dots for the other stars in the *nakṣatra* constellation.

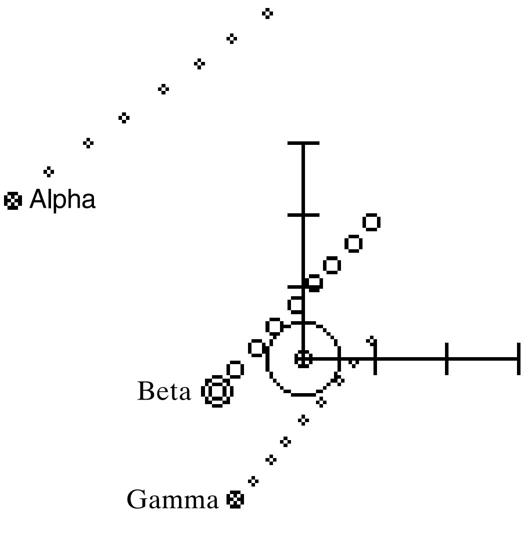
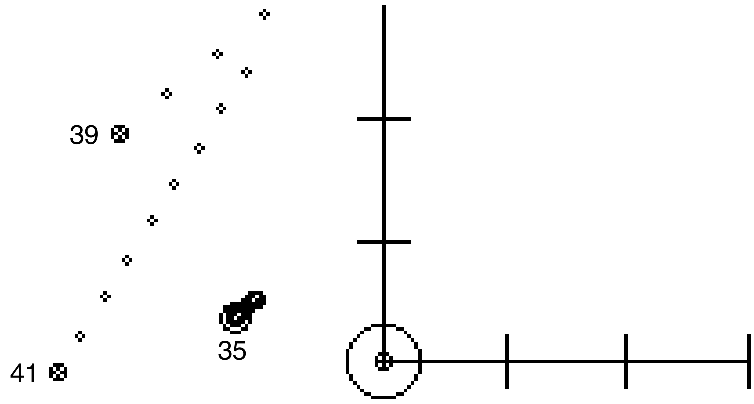


Figure 1. Aśvinī. Burgess concludes that this *nakṣatra* consists of Beta and Gamma Arietis (and perhaps Alpha Arietis). According to the *Sūrya-siddhānta*, the *yogatārā* is the northern star; Colebrooke selects Alpha for the *yogatārā*, but Burgess chooses Beta on the basis of position and sastric references indicating that Aśvinī consists of just two stars.

Beta Arietis is 1.271 degrees from the position of Aśvinī in A.D. 2000, and it reached a minimum distance of .580 degrees in 28,080 B.E. (B.E. means before the epoch of A.D. 2000.)

Figure 2. Bharaṇī. Colebrooke cites testimony indicating that this *nakṣatra* consists of three stars in



Musca Borealis. Burgess identifies these as 35, 41, and 39 Arietis. The *yogatārā* is stated to be the southern star of the group in the *Sūrya-siddhānta*, and this should be 41. Burgess also suggests 35 on the basis of position.

It turns out that 35 Arietis barely moves in the last 50,000 years. However, 41 Arietis reaches a minimum distance of 2.242 degrees from the *yogatārā*'s position in 40,780 B.E. Since the angle of approach is 56.667 degrees, this represents only a modest decrease in the original distance in A.D. 2000.

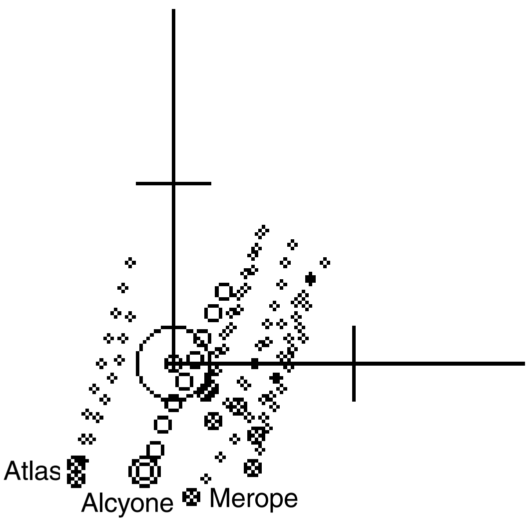


Figure 3. Kṛttikā. Colebrooke and Burgess agree that the *nakṣatra* Kṛttikā consists of six stars of the Pleiades. These six stars are associated with six wives of the Sapta Ṛṣis (the seven sages) who became foster mothers of Kārtikeya. (We show more than six stars, since it is hard to know which six were intended.)

Burgess notes that the southern star of this group should be the *yogatārā*, according to the *Sūrya-siddhānta*, and this would be Atlas (27 Tauri) or Merope (23 Tauri). However, Alcyone (Eta Tauri) is the brightest in the group, and he concludes that it must be the *yogatārā*.

In 2000 A.D. Alcyone is .613 degrees from the *yogatārā* position, but in 45,370 B.E. this distance was at a minimum of 0.093 degrees.

Figure 4. Rohiṇī. Colebrooke and Burgess agree that Aldebaran (Alpha Tauri) is the *yogatārā* of this *nakṣatra*. Burgess and Kay list its other stars as Theta, Gamma, Delta, and Epsilon Tauri. Aldebaran is the eastern star of this group, as required by the *Sūrya-siddhānta*.

As we go back in time, Aldebaran moves toward Rohiṇī at an angle of 8.524 degrees. It is closest to Rohiṇī at a distance of .245 degrees in 28,620 B.E.

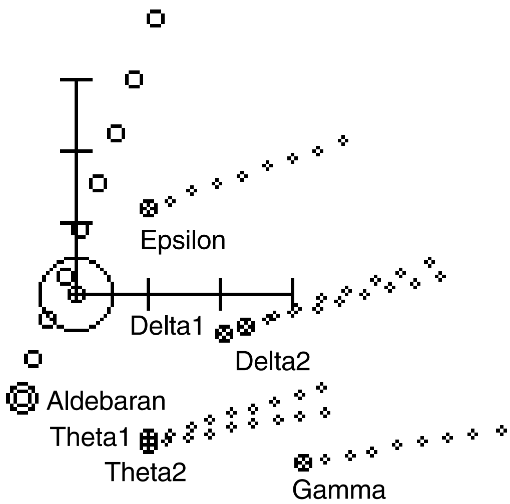
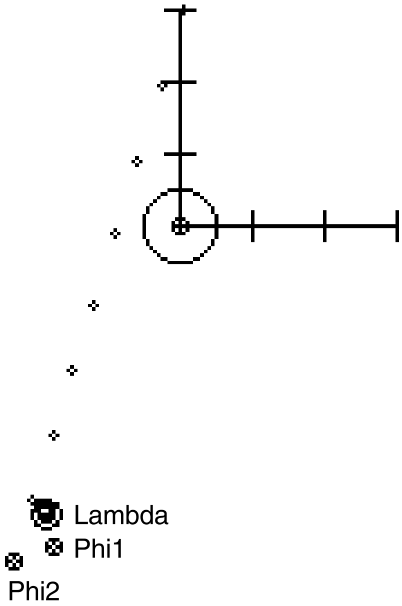


Figure 5. Mṛgaśīrṣa. Colebrooke and Burgess agree that this *nakṣatra* must consist of the three stars in



the head of Orion (Lambda, Phi1, and Phi2 Orionis). Of these, the northern star should be the *yogatārā* according to *Sūrya-siddhānta*, and this is Lambda.

It turns out that Lambda Orionis barely moves from its position in a period of 50,000 years. However, as we go back in time, Phi2 Orionis moves towards the Mṛgaśīrṣa position at an angle of 9.204 degrees, and it was at a minimum distance of .830 degrees in 57,640 B.E.

Figure 6. Ārdrā. Both Colebrooke and Burgess agree that this *nakṣatra* should consist of the single star Betelgeuse (Alpha Orionis). However, Burgess is dissatisfied, since Betelgeuse is 6.261 degrees from the position of Ārdrā. He suggests a dim star, 135 Tauri that is closer to this position, but notes that neither star is of the third magnitude, as required by the verse in *Sūrya-siddhānta* describing the heliacal rising of Ārdrā. He concludes that, "We confess ourselves unable to account for the confusion existing with regard to this asterism, of which al-Biruni also could obtain no intelligible account from his Indian teachers."

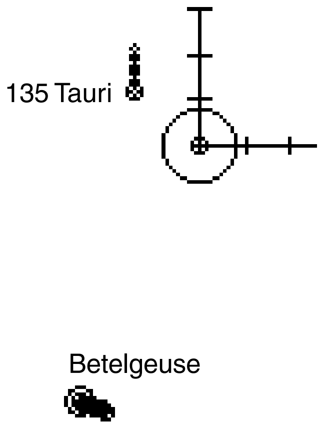
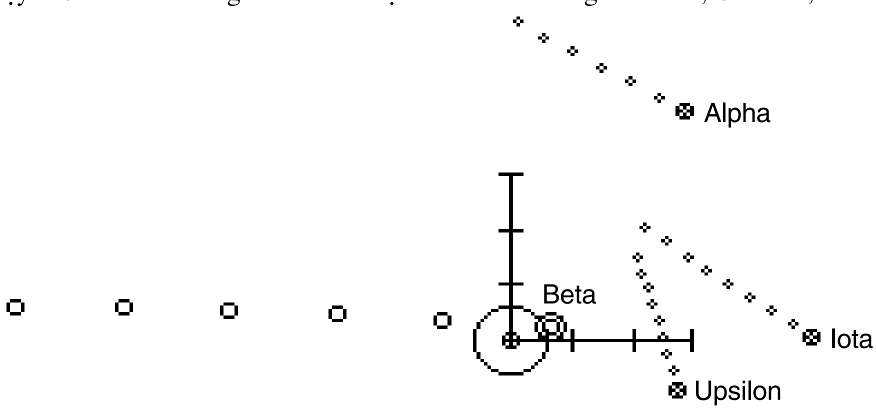
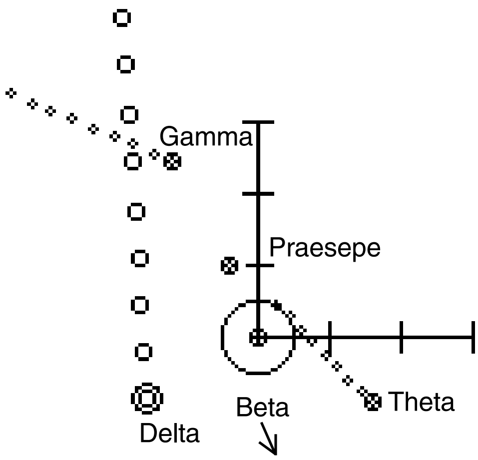


Figure 7. Punarvasu. Some authorities assign two stars to this *nakṣatra*, and Colebrooke and Burgess agree that these should be Alpha and Beta Geminorum. Others say that there are four stars, and thus Colebrooke adds Theta and Tau Geminorum and Burgess adds Iota and Upsilon Geminorum. The *yogatārā* should be to the east according to the *Sūrya-siddhānta*, and this star is Beta Geminorum.

Going back in time, Beta Geminorum approaches the *yogatārā* position at a 26.553 degree angle, reaching a minimum distance of 0.305 degrees in 3520 B.E.

Figure 8. Puṣya. Colebrooke regards this *nakṣatra* as consisting of Delta, Gamma, and Beta Cancri,





and Burgess chooses Delta, Gamma, and Theta or Beta, Gamma, and Theta, and the nebulous cluster, Praesepe. The middle star is the *yogatārā*, according to the *Sūrya-siddhānta*, and this would be Delta for the first Burgess selection and Theta for the second.

Burgess notes that Theta is now dim (magnitude 5.35), but Ptolemy lists it as having a magnitude of 4. In general, it appears that the luminosity of stars can vary considerably over thousands of years.

As we go back in time, Theta moves from a distance of 1.819 degrees from Puṣya in A.D. 2000 to .765 degrees in 50,000 B.E. and a minimum of 0.505 degrees in 75,550 B.E.

Figure 9. Āśleṣā. Colebrooke argued that this *nakṣatra* should be Alpha Cancri plus four other unidentified stars. Burgess pointed out that suitable stars were not to be found near Alpha Cancri, and suggested that the *nakṣatra* should consist of Epsilon, Eta, Sigma, Delta, and Rho Hydrae, with Epsilon as the *yogatārā*. All of these stars are shown in the figure.

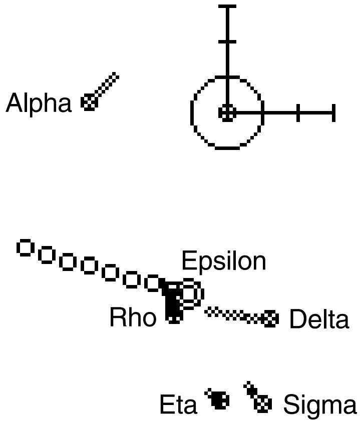
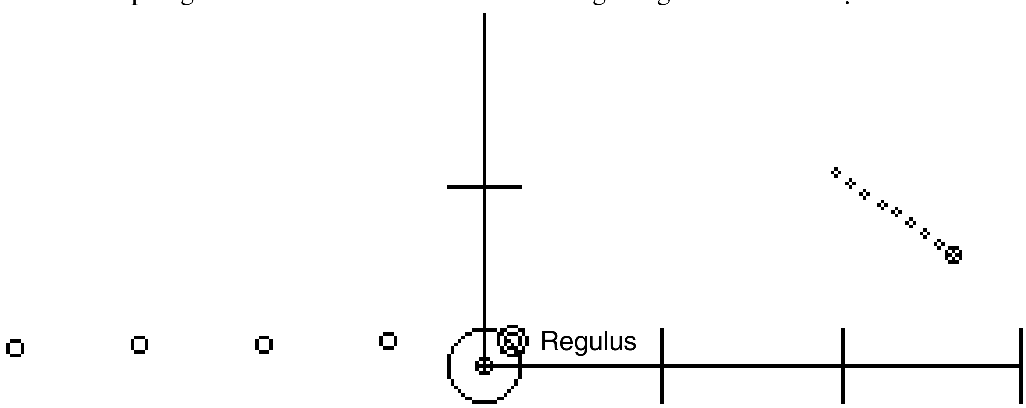
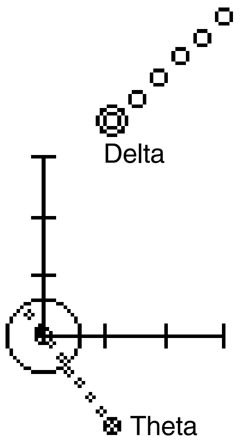


Figure 10. Maghā. Colebrooke and Burgess agree that Regulus (Alpha Leonis) is the *yogatārā* of this *nakṣatra*, but they express some indecision regarding the remaining stars in the group. Their best suggestion seems to be that this *nakṣatra* corresponds to the constellation known as the Sickle: Alpha, Eta, Gamma, Zeta, Mu, and Epsilon Leonis.

As we go back in time, Regulus approaches the *yogatārā* position at a 43.313 degree angle, reaching a minimum distance of 0.147 degrees in 2250 B.E.

Figure 11. Pūrvaphalgunī. Here both Colebrooke and Burgess agree that the *nakṣatra* consists of Delta





and Theta Leonis. The *Sūrya-siddhānta* indicates that the *yogatārā* is the northern star, and this is Delta Leonis. However, Colebrooke suggests that Brahmagupta and Bhascara selected the southern star, Theta, as the *yogatārā*, and Burgess makes a similar comment.

In the figure we can see that Theta Leonis was very close to the *yogatārā* position about 60,000 years ago. In fact, it was at a distance of .02 degrees in 65,560 B.E. Delta, however, moves further from this position as we go back in time.

Figure 12. Uttaraphalgunī. Colebrooke and Burgess agree that Beta Leonis should be the *yogatārā* of this *nakṣatra*, but there is some confusion regarding the other stars. If there are two in total, Burgess suggests 93 Leonis for the other. However, this is to the north of Beta, and the *Sūrya-siddhānta* says that the *yogatārā* should be the northern star. Sakalya gives the *nakṣatra* five stars, and Burgess suggests that these might be Beta Leonis and probably Xi1, Nu, Pi, and Omicron Virginis.

As we go back in time, Beta Leonis moves away from the *yogatārā* position at an angle of 145.010 degrees.

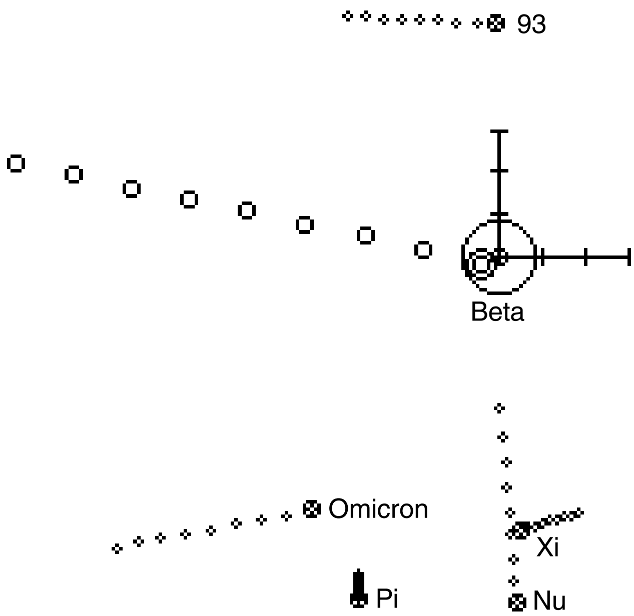


Figure 13. Hasta. Colebrooke and Burgess agree that this *nakṣatra* consists of Alpha, Beta, Gamma, Delta, and Epsilon Corvi. Burgess points out that the description in *Sūrya-siddhānta* of the *yogatārā* is ambiguous, but seems to indicate Gamma. He then goes on to say that "the defined position, in which all authorities agree, would point rather to Delta" (Burgess, p. 334).

Delta Corvi was at a minimum distance of .480 degrees from the position of Hasta in 39,310 B.E.

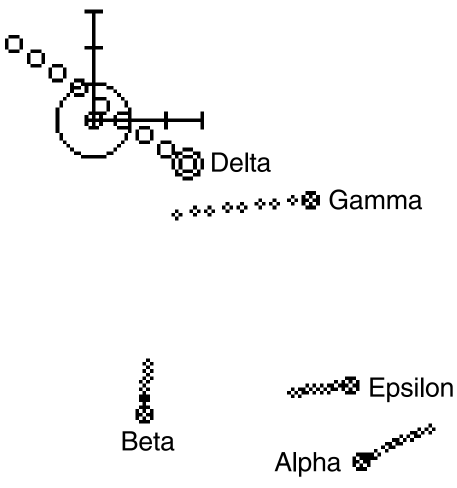
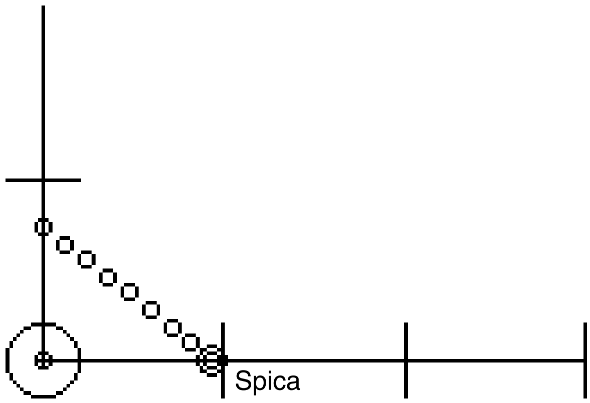
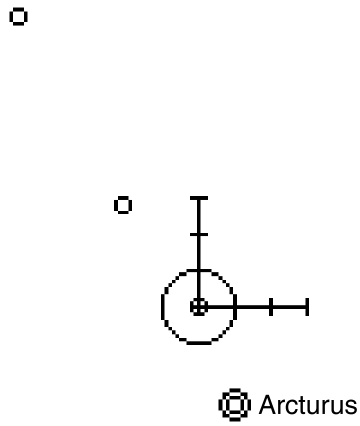


Figure 14. Citrā. Colebrooke and Burgess agree that this *nakṣatra* consists of the single star Spica (Alpha Virginis).



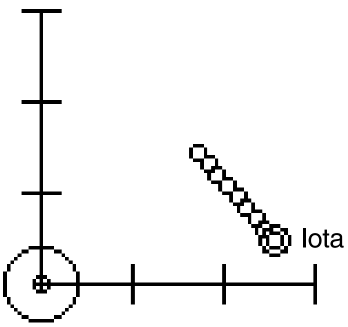
It was situated at a minimum distance of .581 degrees from the *nakṣatra* position in 49,580 B.E.

Figure 15. Svātī. Colebrooke and Burgess agree that this *nakṣatra* consists of the single star Arcturus (Alpha Bootis), and Colebrooke cites native testimony supporting this.



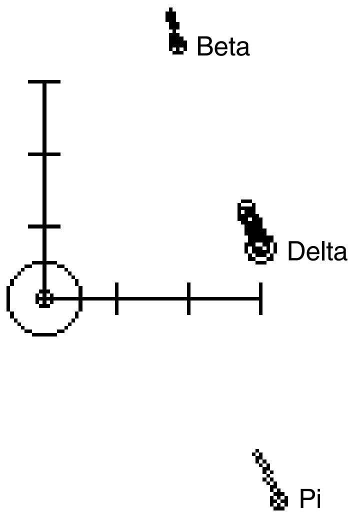
As we go back in time, Arcturus approaches the position of Svātī at an 8.638 degree angle, reaching a minimum distance of 0.432 degrees in 4500 B.E. The distance in A.D. 2000 is 2.851 degrees.

Figure 16. Viśākhā. There is considerable confusion in the identification of the stars making up this *nakṣatra*. Colebrooke concludes that the stars are Alpha, Nu, and Iota Librae and Gamma Scorpionis, with Alpha Librae as the *yogatārā*. Burgess disagrees and chooses Iota, Alpha, Beta, and Gamma Librae. He argues on the basis of position that Iota should be the *yogatārā*. Since some authorities say that this *nakṣatra* should have two rather than four stars, and the *yogatārā* should be the northern star, he also suggests that Viśākhā might consist of Iota Librae and 20 Librae to the south. At this point he complains that, "The whole scheme of designations we regard as of inferior authenticity, and as partaking of the confusion and uncertainty of the later knowledge of the Hindus respecting their system of asterisms."



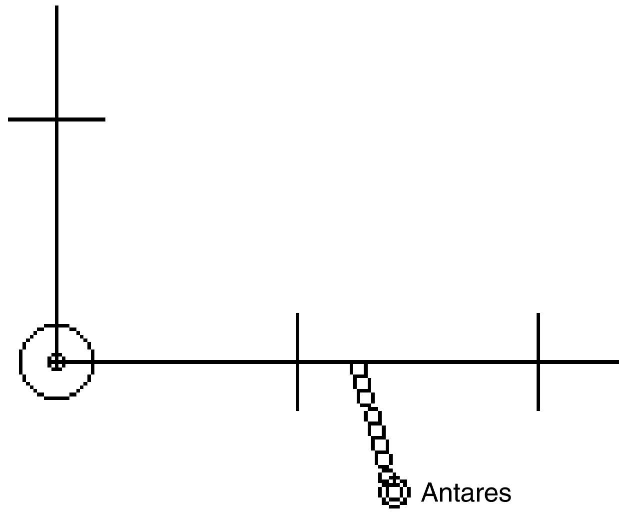
As we go back in time, Iota Librae moves in the direction of the *yogatārā* position at an angle of 59.600 degrees, reaching a minimum distance of 2.235 degrees in 82,760 B.E.

Figure 17. Anurādhā. Both Colebrooke and Burgess agree that this



nakṣatra should contain Beta, Delta, and Pi Scorpionis, with Delta as the *yogatārā*. Rho Scorpionis may also be included.

Figure 18. Jyeṣṭha. Colebrooke and Burgess agree that this *nakṣatra* consists of Alpha, Sigma, and Tau Scorpionis, and that the *yogatārā* is Antares (Alpha Scorpionis). Antares was 1.499 degrees from Jyeṣṭha's position in A.D. 2000, and it reached a minimum distance of 1.200 degrees in 134,760 B.E.



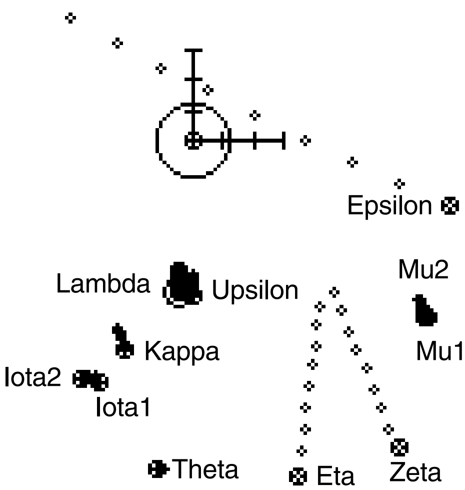


Figure 19. Mūla. Colebrooke and Burgess agree that this *nakṣatra* should consist of the stars Upsilon, Lambda, Kappa, Iota, Theta, Eta, Zeta, Mu, and Epsilon Scorpionis that form the tail of the scorpion.

The *Sūrya-siddhānta* says that the *yogatārā* is the eastern star of the group, and this is Iota. However, Colebrooke selects Upsilon and Burgress selects Lambda. This is done on the basis of position and agreement with the Arabic manzil ash-Shaulan, which consists of Upsilon and Lambda.

It turns out that Upsilon and Lambda barely move over a 50,000 year period. However, the figure shows that the star Epsilon reached a minimum distance of 1.667 degrees from the position of Mūla in 48,223 B.E.

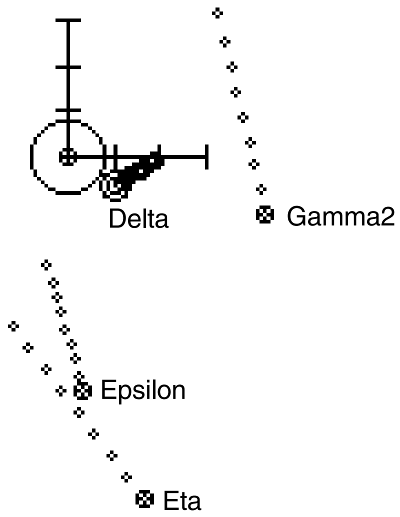
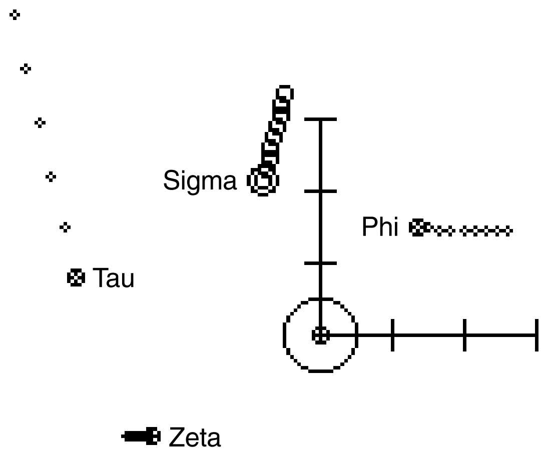


Figure 20. Pūrvaṣāḍhā. Colebrooke and Burgess agree that if two stars are intended for this *nakṣatra*, these should be Delta and Epsilon Sagittarii, with Delta as the *yogatārā*. Sakalya assigns four stars to this *nakṣatra*, and Burgess proposes that these should be Gamma2, Delta, Epsilon, and Eta Sagittarii; this is also stated by Alberuni.

Figure 21. Uttaraṣāḍhā. Colebrooke assigns the two stars Tau and Zeta Sagittarii to this *nakṣatra*, with Tau as the *yogatārā*. Burgess assigns Sigma and Zeta Sagittarii, with Sigma as the *yogatārā*. Sakalya assigns four stars to Uttaraṣāḍhā, and Burgess suggests that these should be Phi, Sigma, Tau, and Zeta Sagittarii; this is also stated by Alberuni. We also note that M. Biot assigns Tau Sagittarii as the *yogatārā*.



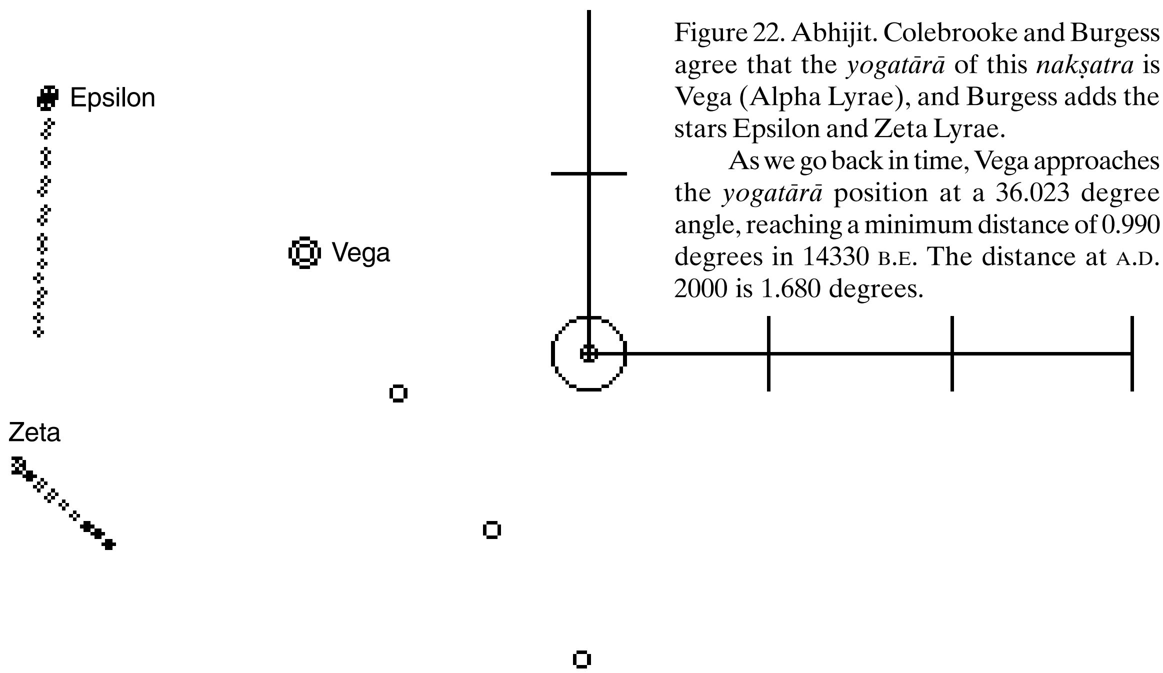


Figure 22. Abhijit. Colebrooke and Burgess agree that the *yogatārā* of this *nakṣatra* is Vega (Alpha Lyrae), and Burgess adds the stars Epsilon and Zeta Lyrae.

As we go back in time, Vega approaches the *yogatārā* position at a 36.023 degree angle, reaching a minimum distance of 0.990 degrees in 14330 B.E. The distance at A.D. 2000 is 1.680 degrees.

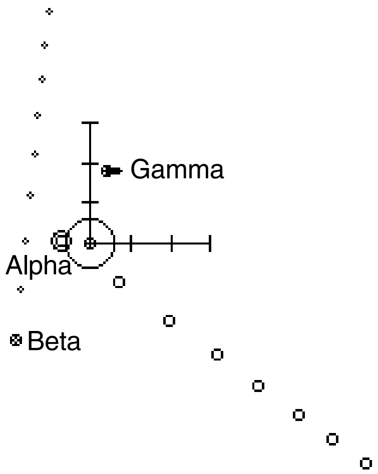


Figure 23. Śravaṇa. Colebrooke and Burgess agree that this *nakṣatra* consists of Alpha, Beta, and Gamma Aquilae, with Alpha as the *yogatārā*.

As we go back in time, this star approaches the *yogatārā* position at a 32.233 degree angle, reaching a minimum distance of 0.378 degrees in 3430 B.E.

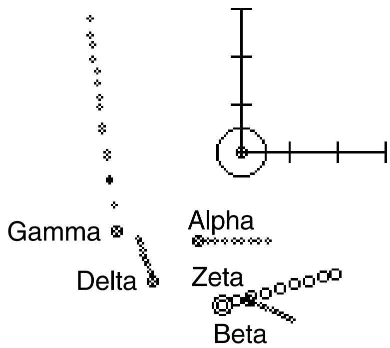


Figure 24. Śraviṣṭhā or Dhaniṣṭhā. Colebrooke reports testimony from Jesuits in India indicating that this *nakṣatra* should consist of Alpha, Beta, Gamma, and Delta Delphini. Burgess agrees and notes that the *yogatārā* should be the westernmost star, according to *Sūrya-siddhānta*. This should be Beta, although Burgess also suggests Zeta Delphini as a possibility.

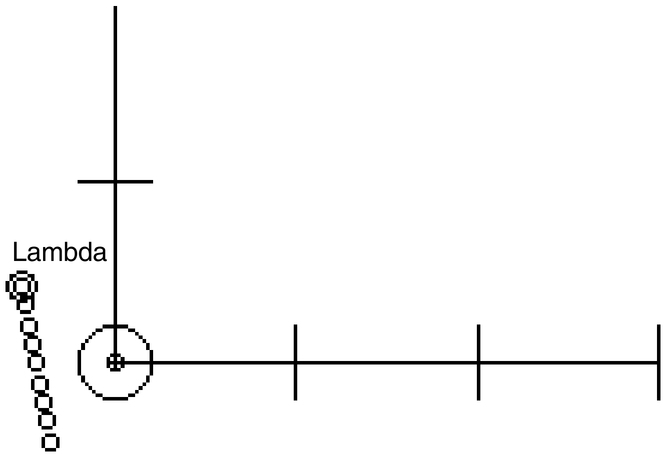


Figure 25. Śatabhiṣaj. Colebrooke and Burgess agree that this *nakṣatra* consists of 100 stars in the stream from the Jar or in the right leg of Aquarius. They identify the *yogatārā* as Lambda Aquarii. This star reached its minimum distance from the *yogatārā* position at .434 degrees in 46,760 B.E.

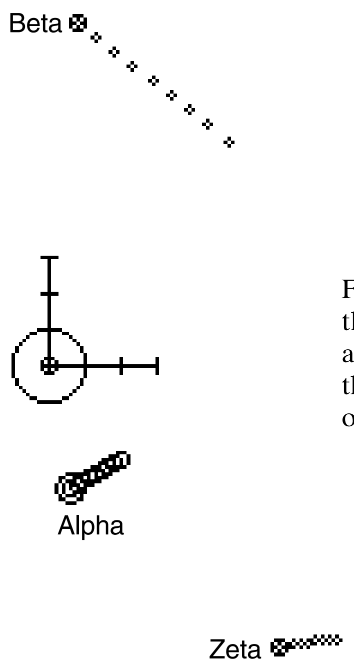


Figure 26. Pūrvabhādrapadā. Both Colebrooke and Burgess argue that this *nakṣatra* should consist of Alpha and Zeta Pegasi or perhaps Alpha and Beta Pegasi. They choose Alpha as the *yogatārā*, and in the first case this will be the northern star, as required by the *Sūrya-siddhānta*. All three of these stars are shown in the figure.

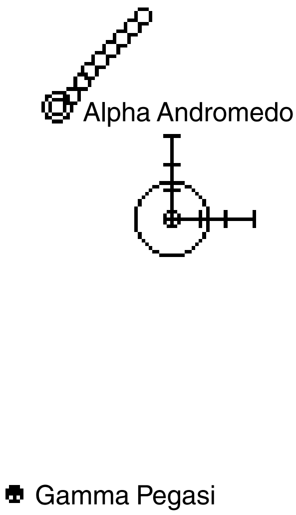


Figure 27. Uttarabhādrapadā. Both Colebrooke and Burgess agree that this *nakṣatra* should consist of Alpha Andromedo and Gamma Pegasi. Colebrooke chooses Alpha Andromedo as the *yogatārā*.

However, Burgess suggests that Alpha and Gamma Pegasi were originally the southern junction stars of the two Bhādrapadās, (see Pūrvabhādrapadā above) and that the rank of junction star was for some reason transferred to the northern stars in the two asterisms. He says, "in making the transfer, the original constitution of the former group [Pūrvabhādrapadā] was neglected, while in the latter [Uttarabhādrapadā] the attempt was made to define the real position of the northern star, but by simply adding to the polar latitude already stated for Gamma Pegasi, without altering its polar longitude also." Thus, he maintains, Uttarabhādrapadā was assigned the longitude of Gamma Pegasi and the latitude of Alpha Andromedo.

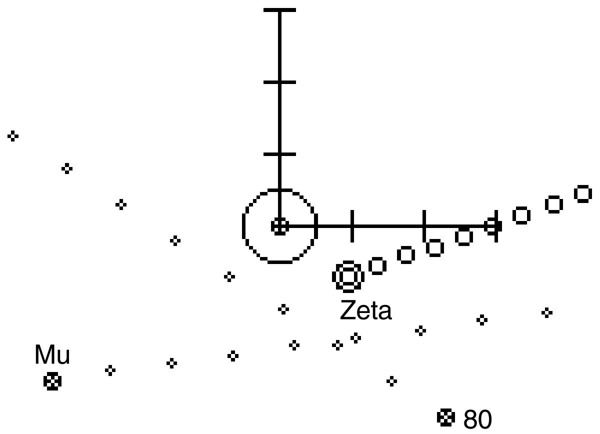


Figure 28. Revatī. Colebrooke, Burgess, and most other authorities on Indian astronomy agree that the *yogatārā* of this *nakṣatra* should be Zeta Piscium. There are said to be 31 other stars in this *nakṣatra*, but their identity seems to be unknown. The *yogatārā* of Revatī is important, since it is used as the starting point for measurements of celestial longitude in ancient Indian astronomy. However, it is a dim star (of magnitude 4.86) and is one of those which Alberuni was unable to identify.

As we go back in time, Zeta Piscium moves sharply away from the *yogatārā* position at an angle of 125.959 degrees.

We have included two additional nearby stars, Mu and 80 Piscium, that do move towards Revatī's position as we go back in time. However, these have not been assigned to this *nakṣatra* by Burgess.

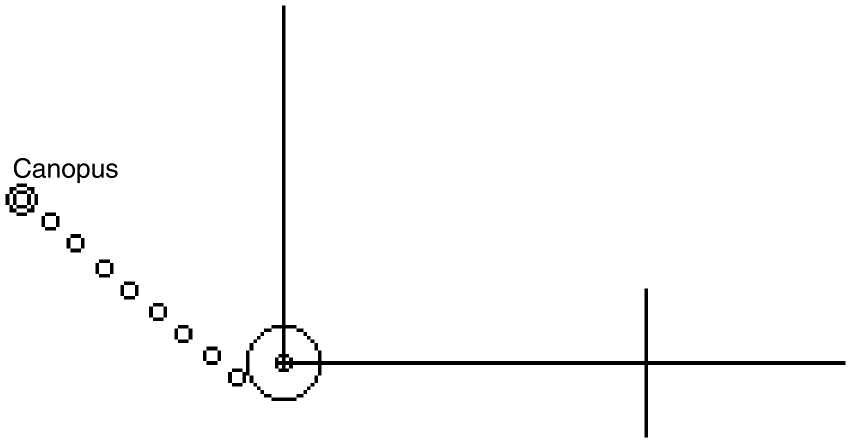


Figure 29. Agastya. Colebrooke and Burgess agree that Agastya is Canopus (Alpha Carinae). This star was at a minimum of 0.113 degrees from Agastya's position 87,500 B.E., and was 0.377 degrees away at 50,000 B.E.

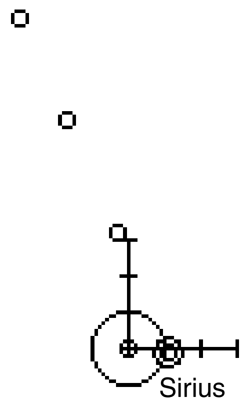


Figure 30. Mṛgavyādha. Colebrooke and Burgess agree that this star is Sirius (Alpha Canis Major). Going back in time, Sirius approaches the position of Mṛgavyādha at a 62.610 degree angle, reaching a minimum distance of 0.995 degrees in 1430 B.E. The distance at A.D. 2000 is 1.119 degrees, and thus Sirius only roughly approaches Mṛgavyādha.

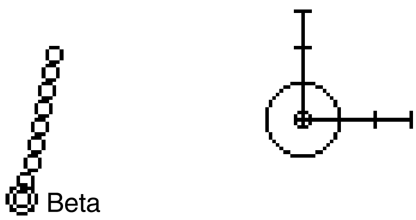


Figure 31. Agni or Hutabhuj (31). Both Colebrooke and Burgess regard this star as Beta Tauri.

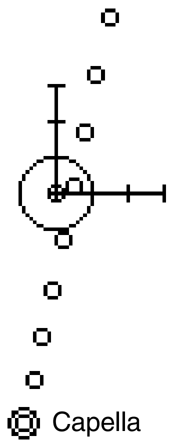


Figure 32. Brahmahṛdaya. Burgess identifies this star as Capella (Alpha Aurigae).
The figure shows that Capella was very close to the position of Brahmahṛdaya about 50,000 years ago. Its distance will be 6.487 degrees in A.D. 2000, and it reached a minimum value of 0.453 degress in 48,164 B.E.

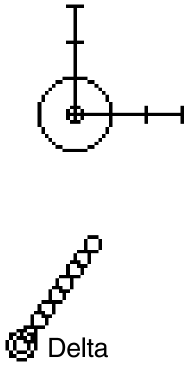


Figure 33. Prajāpati. Colebrooke and Burgess agree that Prajāpati is Delta Aurigae. As we can see in the figure, this star approaches the position of Prajāpati as we move back in time, but it takes 143,600 years before it reaches its minimum distance of 2.449 degrees. At 50,000 B.E. the distance is still 4.687 degrees.

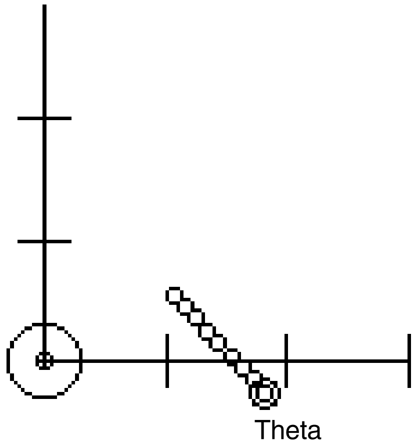


Figure 34. Apāmvatsa. Burgess identifies this star as Theta Virginis, and Colebrooke's identification is unclear. This star was somewhat closer to the position of Apamvatsa in 50,000 B.E., and it reached a minimum distance of 1.161 degrees in 102,360 B.E.

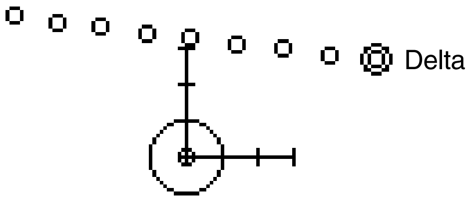


Figure 35. Āpas. Colebrooke and Burgess agree that this star is Delta Virginis. Going back in time, Delta Virginis went from a distance of 5.910 degrees from Apas in A.D. 2000 to a minimum distance of 3.296 degrees in 37,370 B.E.