XIII. REMARKS *on the ASTRONOMY of the BRAHMINS.*

*By JOHN PLAYFAIR, A. M. F. R. S. EDIN. and
Professor of Mathematics in the University of Edinburgh.*

[*Read by the Author, March 2. 1789.*]

1. **S**INCE the time when Astronomy emerged from the obscurity of ancient fable, nothing is better known than its progress through the different nations of the earth. With the era of NABONASSAR, regular observations began to be made in Chaldea; the earliest which have merited the attention of succeeding ages. The curiosity of the Greeks was, soon after, directed to the same object; and that ingenious people was the first that endeavoured to explain, or connect by theory, the various phenomena of the heavens. This work was supposed to be so fully accomplished in the Syntaxis of PTOLEMY, that his system, without opposition or improvement, continued, for more than five hundred years, to direct the Astronomers of Egypt, Italy and Greece. After the sciences were banished from Alexandria, his writings made their way into the east, where, under the Caliphs of Bagdat, Astronomy was cultivated with diligence and success. The Persian Princes followed the example of those of Bagdat, borrowing besides, from Trebifond, whatever mathematical knowledge was still preserved among the ruins of the Grecian empire. The conquests of GENGIS, and afterwards of TIMOUR, though they retarded, did not stop the progress of Astronomy in the east. The grandsons of these two conquerors were equally renowned for
their

their love of science: HULAGU restored Astronomy in Persia, and ULUGH-BEIGH, by an effort still more singular, established it in Tartary. In the mean time, having passed with the Arabs into Spain, it likewise found, in ALPHONSO of Castile, both a disciple and a patron. It was carried, soon after, into the north of Europe, where, after exercising the genius of COPERNICUS, of KEPLER, and of NEWTON, it has become the most perfect of all the sciences.

2. IN the progress which Astronomy has thus made, through almost all the nations, from the Indus to the Atlantic, there is scarce a step which cannot be accurately traced; and it is never difficult to determine what each age, or nation received from another, or what it added to the general stock of astronomical knowledge. The various systems, that have prevailed in all these countries, are visibly connected with one another; they are all derived from one original, and would incline us to believe, that the manner in which men begin to observe the heavens, and to reason about them, is an experiment on the human race, which has been made but once.

It is, therefore, matter of extreme curiosity to find, beyond the Indus, a system of astronomical knowledge that appears to make no part of the great body of science, which has traversed, and enlightened the other countries of the earth; a system that is in the hands of men, who follow its rules without understanding its principles, and who can give no account of its origin, except that it lays claim to an antiquity far beyond the period, to which, with us, the history of the heroic ages is supposed to extend.

3. WE owe our first knowledge of this astronomy to M. LA LOUBERE, who, returning, in 1687, from an embassy to Siam, brought with him an extract from a Siamese manuscript, which contained tables, and rules, for calculating the places of the sun and moon *. The manner in which these rules were laid
down

* Mem. de l'Acad. des Sciences, tom. 8. p. 281. &c.

down, rendered the principles, on which they were founded, extremely obscure ; and it required a commentator, as conversant with astronomical calculation as the celebrated CASSINI, to explain the meaning of this curious fragment. After that period, two other sets of astronomical tables were sent to Paris, by the missionaries in HINDOSTAN ; but they remained unnoticed, till the return of M. LE GENTIL from India, where he had been to observe the transit of Venus in 1769. This Academician employed himself, during the long stay, which his zeal for science induced him to make in that country, in acquiring a knowledge of the Indian astronomy. The Brahmins thought they saw, in the business of an Astronomer, the marks of a *Cassini*, that had some affinity to their own, and began to converse with M. LE GENTIL, more familiarly than with other strangers. A learned Brahmin of Tirvalore, having made a visit to the French Astronomer, instructed him in the methods, which he used for calculating eclipses of the sun and moon, and communicated to him the tables and rules, that are published in the Memoirs of the Academy of Sciences, for 1772. Since that time, the ingenious and eloquent author of the History of Astronomy, has dedicated an entire volume to the explanation, and comparison of these different tables, where he has deduced, from them, many interesting conclusions *. The subject indeed merited his attention ; for the Indian astronomy has all the precision necessary for resolving the great questions, with respect to its own origin and antiquity, and is by no means among the number of those imperfect fragments of ancient knowledge, which can lead no farther than conjecture, and which an Astronomer would gladly resign to the learned researches of the Antiquary, or the Mythologist.

4. IT is from these sources, and chiefly from the elaborate investigations of the last mentioned work, that I have selected

VOL. II.

f

the

* *Traité de l'Astronomie Indienne et Orientale*, par M. BAILLY. Paris, 1787.

the materials of the paper, which I have now the honour to lay before this Society ; and it is perhaps necessary that I should make some apology for presenting here, what can have so little claim to originality. The fact is, that notwithstanding the most profound respect, for the learning and abilities of the author of the *Astronomie Indienne*, I entered on the study of that work, not without a portion of the scepticism, which whatever is new and extraordinary in science ought always to excite, and set about verifying the calculations, and examining the reasonings in it, with the most scrupulous attention. The result was, an entire conviction of the accuracy of the one, and of the solidity of the other ; and I then fancied, that, in an argument of such variety, I might perhaps do a service to others, by presenting to them, that particular view of it, which had appeared to me the most striking. Such, therefore, is the object of these remarks ; they are directed to three different points : The first is to give a short account of the Indian astronomy, so far as it is known to us, from the four sets of tables above mentioned ; the second, to state the principal arguments, that can be deduced from these tables, with respect to their antiquity ; and the third, to form some estimate of the geometrical skill, with which this astronomical system is constructed. In the first, I have followed M. BAILLY closely ; in the second, though I have sometimes taken a different road, I have always come to the same conclusion ; having aimed at nothing so much, as to reduce the reasoning into a narrow compass, and to avoid every argument that is not purely astronomical, and independent of all hypothesis ; in the third, I have treated of a question which did not fall within the plan of M. BAILLY's work, but have only entered on it at present, leaving to some future opportunity, the other discussions to which it leads.

5. THE astronomy of India, as you already perceive, is confined to one branch of the science. It gives no theory, nor even any description of the celestial phenomena, but satisfies
itself

itself with the calculation of certain changes in the heavens, particularly of the eclipses of the sun and moon, and with the rules and tables by which these calculations must be performed. The Brahmin, seating himself on the ground, and arranging his shells before him, repeats the enigmatical verses that are to guide his calculation; and from his little tablets of palm leaves, takes out the numbers that are to be employed in it. He obtains his result with wonderful certainty and expedition; but having little knowledge of the principles on which his rules are founded, and no anxiety to be better informed, he is perfectly satisfied, if, as it usually happens, the commencement and duration of the eclipse answer, within a few minutes, to his prediction. Beyond this his astronomical enquiries never extend; and his observations, when he makes any, go no farther than to determine the meridian line, or the length of the day, at the place where he observes.

THE objects, therefore, which this astronomy presents to us, are principally three. 1. Tables and rules for calculating the places of the sun and moon: 2. Tables and rules for calculating the places of the planets: 3. Rules by which the phases of eclipses are determined. Though it is chiefly to the first of these that our attention at present is to be directed, the two last will also furnish us with some useful observations.

6. THE Brahmins, like all other Astronomers, have distinguished from the rest of the heavens, that portion of them, through which the sun, moon and planets continually circulate. They divide this space, which we call the zodiac, into twenty-seven equal parts, each marked by a group of stars, or a constellation*. This division of the zodiac is extremely natural in the infancy of astronomical observation; because the moon completes her circle among the fixed stars, nearly in twenty-seven days, and so makes an actual division of that circle

$\int 2$ into

* Mem. sur l'Astronomie des Indiens, par M. LE GENTIL, Hist. de l'Acad. des Scien. 1772, II. P. 207. The phrase which we here translate *constellations*, signifies the places of the moon in the twelve signs.

into twenty-seven equal parts. The moon too, it must be remembered, was, at that time, the only instrument, if we may say so, by which the positions of the stars on each side of her path could be ascertained; and when her own irregularities were unknown, she was, by the rapidity of her motion eastward, well adapted for this purpose. It is also to the phases of the moon, that we are to ascribe the common division of time into weeks, or portions of seven days, which seems to have prevailed almost over the whole earth*. The days of the week are dedicated by the Brahmins, as by us, to the seven planets, and what is truly singular, they are arranged precisely in the same order.

7. WITH the constellations, that distinguish the twenty-seven equal spaces, into which their zodiac is divided, the Astronomers of India have connected none of those figures of animals, which are among us, of so ancient, and yet so arbitrary an original. M. LE GENTIL has given us their names, and configurations†. They are formed, for the most part, of small groups of stars, such as the Pleiades or the Hyades, those belonging to the same constellation being all connected by straight lines. The first of them, or that which is placed at the beginning of their zodiac, consists of six stars, extending from the head of Aries to the foot of Andromeda, in our zodiac, and occupying a space of about ten degrees in longitude. These constellations are far from including all the stars in the zodiac. M. LE GENTIL remarks, that those stars seem to have been selected, which are best adapted for marking out, by lines drawn between them, the places of the moon in her progress through the heavens.

AT the same time that the stars in the zodiac are thus arranged into twenty-seven constellations, the ecliptic is divided, as with us, into twelve signs of thirty degrees each. This division

* Mem. Acad. des Scien. 1772, II. P. 189.

† Ibid. 209.

vifion is purely ideal, and is intended merely for the purpose of calculation. The names and emblems by which these figns are expreffed, are nearly the fame as with us *; and as there is nothing in the nature of things to have determined this coincidence, it muft, like the arrangement of the days of the week, be the refult of fome ancient and unknown communication.

8. THAT motion by which the fixed ftars all appear to move eastward, and continually to increafe their diftance from the place, that the fun occupies at the vernal equinox, is known to the Brahmins, and enters into the compofition of all their tables †. They compute this motion to be at the rate of 54" a-year; fo that their *annus magnus*, or the time in which the fixed ftars complete an entire revolution, is 24,000 years. This motion is too quick by fomewhat lefs than 4" a-year; an error that will not be thought great, when it is confidered, that PROLEMY committed one of 14", in determining the fame quantity.

ANOTHER circumftance, which is common to all the tables, and, at the fame time, peculiar to the Indian aftronomy, is, that they exprefs the longitude of the fun and moon, by their diftance from the beginning of the moveable zodiac, and not, as is ufual with us, by their diftance from the point of the vernal equinox. The longitude is reckoned in figns of 30°, as already mentioned, and each degree is fubdivided into 60', &c. In the divifion of time, their arithmetic is purely fexagefimal: They divide the day into 60 hours, the hour into 60 minutes, &c.; fo that their hour is 24 of our minutes, their minute 24 of our feconds, and fo on.

9. THESE

* Mem. Acad. des Scien. 1772. II. P. 200. The zodiac they call *jodi mandalam*, or the circle of ftars.

† Ibid. 194. Aft. Indienne, p. 43, &c.

9. THESE remarks refer equally to all the tables. We are now to take notice of what is peculiar to each, beginning with those of Siam.

IN order to calculate for a given time, the place of any of the celestial bodies, three things are requisite. The first is, the position of the body in some past instant of time, ascertained by observation; and this instant, from which every calculation must set out, is usually called the *epoch* of the tables. The second requisite is, the mean rate of the planet's motion, by which is computed the arch in the heavens, that it must have described, in the interval between the epoch and the instant for which the calculation is made. By the addition of this, to the place at the epoch, we find the mean place of the planet, or the point it would have occupied in the heavens, had its motion been subject to no irregularity. The third is, the correction, on account of such irregularity, which must be added to the mean place, or subtracted from it, as circumstances require, in order to have the true place. The correction thus made is, in the language of astronomy, called an *equation*; and, when it arises from the eccentricity of a planet's orbit, it is called the *equation of the centre*.

10. THE epoch of the tables of Siam does not go back to any very remote period. M. CASSINI, by an ingenious analysis of their rules, finds that it corresponds to the 21st of March, in the year 638 of our era, at 3 in the morning, on the meridian of Siam*. This was the instant at which the astronomical year began, and at which both the sun and moon entered the moveable zodiac. Indeed, it is to be observed, that, in all the tables, the astronomical year begins when the sun enters the moveable zodiac, so that the beginning of this year is continually advancing with respect to the seasons, and makes the complete round of them in 24,000 years.

FROM

* Mem. Acad. Scien. tom. 8. p. 312. Ast. Indienne, p. 11. § 14.

FROM the epoch above mentioned, the mean place of the sun for any other time is deduced, on the supposition that in 800 years, there are contained 292,207 days *. This supposition involves in it the length of the syderial year, or the time that the sun takes to return to the beginning of the moveable zodiac, and makes it consist of 365 *d.* 6 *b.* 12', 36" †. From this, in order to find the tropical year, or that which regulates the seasons, we must take away 21', 55", as the time which the sun takes to move over the 54", that the stars are supposed to have advanced in the year; there will remain 365 *d.* 5 *b.* 50', 41", which is the length of the tropical year that is involved, not only in the tables of Siam, but likewise, very nearly, in all the rest ‡. This determination of the length of the year is but 1', 53", greater than that of DE LA CAILLE, which is a degree of accuracy beyond what is to be found in the more ancient tables of our astronomy.

II. THE next thing with which these tables present us, is a correction of the sun's mean place, which corresponds to what we call the equation of his centre, or the inequality arising from the eccentricity of his orbit, in consequence of which, he is alternately retarded and accelerated, his true place being, for one half of the year, left behind the mean, and, for the other, advanced before it. The point where the sun is placed, when his motion is slowest, we call his apogee, because his distance from the earth is then greatest; but the Indian astronomy, which is silent with respect to theory, treats this point as nothing more than what it appears to be, a point, *viz.* in the heavens, where the sun's motion is the slowest possible, and about 90° distant from that, where his greatest inequality takes place. This greatest inequality is here made to be

* Aft. Ind. p. 7. § 5.

† Mem. Acad. Scien. tom. 8. p. 328.

‡ Aft. Ind. p. 124. The tables of Tirvalore make the year 6" less.

be 2° , $12'$ *, about $16'$ greater than it is determined, by the modern astronomy of Europe. This difference is very considerable; but we shall find that it is not to be ascribed wholly to error, and that there was a time when the inequality in question was nearly of the magnitude here assigned to it. In the other points of the sun's path, this inequality is diminished, in proportion to the sine of the mean distance from the apogee, that is, nearly as in our own tables. The apogee is supposed to be 80° advanced beyond the beginning of the zodiac, and to retain always the same position among the fixed stars, or to move forward at the same rate with them†. Though this supposition is not accurate, as the apogee gains upon the stars about $10''$ annually, it is much nearer the truth than the system of PTOLEMY, where the sun's apogee is supposed absolutely at rest, so as continually to fall back among the fixed stars, by the whole quantity of the precession of the equinoxes‡.

12. IN these tables, the motions of the moon are deduced, by certain intercalations, from a period of nineteen years, in which she makes nearly 235 revolutions; and it is curious to find at Siam, the knowledge of that cycle, of which the invention was thought to do so much honour to the Athenian Astronomer METON, and which makes so great a figure in our modern

* THE equation of the sun, or what they call the *chaiaa*, is calculated in the Siamese tables only for every 15° of the *matteomme*, or mean anomaly. CASSINI, *ubi supra*, p. 299.

† Aft. Ind. p. 9.

‡ THE error, however, with respect to the apogee, is less than it appears to be; for the motion of the Indian zodiac, being nearly $4'$ swifter than the stars, is but $6''$ slower than the apogee. The velocity of the Indian zodiac is indeed neither the same with that of the stars, nor of the sun's apogee, but nearly a mean between them.

modern kalendars *. The moon's apogee is supposed to have been in the beginning of the moveable zodiac, 621 days after the epoch of the 21st of March 638, and to make an entire revolution in the heavens in the space of 3232 days †. The first of these suppositions agrees with MAYER's tables to less than a degree, and the second differs from them only by 11^b , $14'$, $31''$; and if it be considered that the apogee is an ideal point in the heavens, which even the eyes of an astronomer cannot directly perceive, to have discovered its true motion, so nearly, argues no small correctness of observation.

13. FROM the place of the apogee, thus found, the inequalities of the moon's motion, which are to reduce her mean to her true place, are next to be determined. Now, at the oppositions and conjunctions, the two greatest of the moon's inequalities, the equation of the centre and the evection, both depend on the distance from the apogee, and therefore appear but as one inequality. They also, partly, destroy one another; so that the moon is retarded or accelerated, only by their difference, which, when greatest, is, according to MAYER's tables, 4° , $57'$, $42''$. The Siamese rules, which calculate only for oppositions and conjunctions, give, accordingly, but one inequality to the moon, and make it, when greatest, 4° , $56'$, not $2'$ less than the preceding. This greatest equation is applied, when the moon's mean distance from the apogee is 90° ; in other situations, the equation is less, in proportion as the sine of that distance diminishes ‡.

14. THE Siamese MS. breaks off here, and does not inform us how the astronomers of that country proceed, in the remaining parts of their calculation, which they seem to have undertaken,

VOL. II.

t

taken,

* THE Indian period is more exact than that of our golden number, by $35'$. Aft. Ind. p. 5. The Indians regulate their festivals by this period. *Ibid.* Diac. Prelim. p. viii.

† Aft. Ind. p. 11. & 20.

‡ Aft. Indienne, p. 13. CASSINI Mem. Acad. tom. 8. p. 304.

undertaken, merely for some purpose in astrology. M. CASSINI, to whom we are indebted for the explanation of these tables, observes, that they are not originally constructed for the meridian of Siam, because the rules direct to take away $3'$ for the sun, and $40'$ for the moon, (being the motion of each for 1^b , $13'$), from their longitudes calculated as above *. The meridian of the tables is therefore 1^b , $13'$, or 18° , $15'$, west of Siam; and it is remarkable, that this brings us very near to the meridian of Benares, the ancient seat of Indian learning †. The same agrees nearly with what the Hindoos call their first meridian, which passes through Ceylon and the Banks of Ramanancor. We are, therefore, authorised, or rather, we are necessarily determined to conclude, that the tables of Siam came originally from HINDOSTAN.

15. ANOTHER set of astronomical tables, now in the possession of the Academy of Sciences, was sent to the late M. DE L'ISLE from Chirsnabouram, a town in the Carnatic, by Father DU CHAMP, about the year 1750. Though these tables have an obvious affinity to what have already been described, they form a much more regular and extensive system of astronomical knowledge. They are fifteen in number; and include, beside the mean motions of the sun, moon and planets, the equations to the centre of the sun and moon, and two corrections for each of the planets, the one of which corresponds to its apparent, and the other to its real inequality. They are accompanied also with precepts, and examples, which Father DU CHAMP received from the Brahmins of Chirsnabouram, and which he has translated into French ‡.

THE

* Mem. Acad. Scien. tom. 8. p. 302. & 309.

† Ast. Ind. p. 12. It brings us to a meridian 82° , $34'$, east of Greenwich. Benares is 83° , $11'$, east of the same, by RENNEL's map.

‡ These tables are published by M. BAILLY, Ast. Ind. p. 335, &c. See also p. 31, &c.

THE epoch of these tables is less ancient than that of the former, and answers to the 10th of March at sunrise, in the year 1491 of our era, when the sun was just entering the moveable zodiac, and was in conjunction with the moon; two circumstances, by which almost all the Indian eras are distinguished. The places, which they assign, at that time, to the sun and moon, agree very well with the calculations made from the tables of *MAYER*, and *DE LA CAILLE*. In their mean motions, they indeed differ somewhat from them; but as they do so equally for the sun and moon, they produce no error, in determining the relative position of these bodies, nor, of consequence, in calculating the phenomena of eclipses. The sun's apogee is here supposed to have a motion swifter than that of the fixed stars, by about 1" in nine years, which, though it falls greatly short of the truth, does credit to this astronomy, and is a strong mark of originality. The equation of the sun's centre is somewhat less here than in the tables of Siam; it is $2^{\circ}, 10', 30''$; the equation of the moon's centre is $5^{\circ}, 2', 47''$; her path, where it intersects that of the sun, is supposed to make an angle with it of $4^{\circ}, 30'$, and the motions, both of the apogee and node, are determined very near to the truth.

16. ANOTHER set of tables, sent from India by Father *PATOUILLET*, were received by *M. DE L'ISLE*, about the same time with those of *Chrisnabouram*. They have not the name of any particular place affixed to them; but, as they contain a rule for determining the length of the day, which answers to the latitude of $16^{\circ}, 16'$, *M. BAILLY* thinks it probable that they come from *Narsapour* *.

THE precepts and examples, which accompany these tables, though without any immediate reference to them, are confined to the calculation of the eclipses of the sun and moon; but the tables themselves extend to the motion of the planets, and very much resemble those of *Chrisnabouram*, except that they are given with less detail, and in a form much

* *Astr. Ind.* p. 49, &c.

more enigmatical *. The epoch of the precepts, which M. BAILLY has evolved with great ingenuity, goes back no farther than the year 1569, at midnight, between the 17th and 18th of March. From this epoch, the places of the sun and moon are computed, as in the tables of Siam, with the addition of an equation, which is indeed extremely singular. It resembles that correction of the moon's motion, which was discovered by TYCHO, and which is called the annual equation, because its quantity depends, not on the place of the moon, but on the place of the sun, in the ecliptic. It is every where proportional to the inequality of the sun's motion, and is nearly a tenth part of it. The tables of Narfapour make their annual equation only $\frac{1}{27}$ of the sun's: but this is not their only mistake; for they direct the equation to be added to the moon's longitude, when it ought to be subtracted from it, and *vice versa*. Now, it is difficult to conceive from whence the last mentioned error has arisen; for though it is not at all extraordinary, that the astronomers, who constructed these tables, should mistake the quantity of a small equation, yet it is impossible, that the same observations, which informed them of its existence, should not have determined, whether it was to be added or subtracted. It would seem, therefore, that something accidental must have occasioned this error; but however that be, an inequality in the lunar motions, that is found in no system with which the astronomers of India can have had any communication, is at least a proof of the originality of their tables.

17. THE tables, and methods, of the Brahmins of Tirvalore, are, in many respects, more singular than any that have yet been

* THEY were explained, or rather decyphered by M. LE GENTIL in the Memoirs of the Academy of Sciences for 1784, p. 482, &c.; for they were not understood by the missionary who sent them to Europe, nor probably by the Brahmins who instructed him. M. LE GENTIL thinks that they have the appearance of being copied from inscriptions on stone. The minutes and seconds are ranged in rows under one another, not in vertical columns, and without any title to point out their meaning, or their connection. These tables are published, Mem. Acad. *ibid.* p. 492, and Ast. Ind. p. 414.

been described *. The solar year is divided, according to them, into twelve unequal months, each of which is the time that the sun takes to move through one sign, or 30° , of the ecliptic. Thus, *Any*, or June, when the sun is in the third sign, and his motion slowest, consists of $31^d, 36^b, 38'$, and *Margagy*, or December, when he is in the ninth sign, and his motion quickest, consists only of $29^d, 20^b, 53'$ †. The lengths of these months, expressed in natural days, are contained in a table, which, therefore, involves in it the place of the sun's apogee, and the equation of his centre. The former seems to be 77° from the beginning of the zodiac, and the latter about $2^\circ, 10'$, nearly as in the preceding tables. In their calculations, they also employ an astronomical day, which is different from the natural, being the time that the sun takes to move over one degree of the ecliptic; and of which days there are just 360 in a year ‡.

18. THESE tables go far back into antiquity. Their epoch coincides with the famous era of the Calyougham, that is, with the beginning of the year 3102 before CHRIST. When the Brahmins of Tirvalore would calculate the place of the sun for a given time, they begin by reducing into days the interval between that time, and the commencement of the Calyougham, multiplying the years by $365^d, 6^b, 12', 30''$; and taking away $2^d, 3^b, 32', 30''$, the astronomical epoch having begun that much later than the civil ||. They next find, by means of certain divisions, when the year current began,

* TIRVALORE is a small town on the Coromandel coast, about 12 G. miles west of Negapatnam, in Lat. $10^\circ, 44'$, and east Long. from Greenwich, $79^\circ, 42'$, by RENNEL's map. From the observations of the Brahmins, M. LE GENTIL makes its Lat. to be $10^\circ, 42', 13'$. (Mem. Acad. Scien. II. P. 184.) The meridian of Tirvalore nearly touches the west side of Ceylon, and therefore may be supposed to coincide with the first meridian, as laid down by Father DU CHAMP. There is no reduction of Longitude employed in the methods of Tirvalore.

† These are Indian hours, &c.

‡ Mem. Acad. des Scien. II. P. 187. Ast. Indienne, p. 76, &c.

|| The Indian hours are here reduced to European.

gan, or how many days have elapsed since the beginning of it, and then, by the table of the duration of months, they reduce these days into astronomical months, days, &c. which is the same with the signs, degrees and minutes of the sun's longitude from the beginning of the zodiac. The sun's longitude, therefore, is found.

19. SOMEWHAT in the same manner, but by a rule still more artificial and ingenious, they deduce the place of the moon, at any given time, from her place at the beginning of the Calyougham*. This rule is so contrived, as to include at once the motions both of the moon and of her apogee, and depends on this principle, according to the very skilful interpretation of M. BAILLY, that, 1,600,894 days after the above mentioned epoch, the moon was in her apogee, and $7^{\circ}, 2', 0'', 7''$, distant from the beginning of the zodiac; that after 12,372 days, the moon was again in her apogee, with her longitude increased, $9^{\circ}, 27', 48'', 10''$; that in 3031 days more, the moon is again in her apogee, with $11^{\circ}, 7', 31'', 1''$, more of longitude; and, lastly, that, after 248 days, she is again in her apogee, with $27^{\circ}, 44', 6''$, more of longitude. By means of the three former numbers, they find, how far, at any given time, the moon is advanced in this period of 248 days, and by a table, expressing how long the moon takes to pass through each degree of her orbit, during that period, they find how far she is then advanced in the zodiac†. This rule is strongly marked with all the peculiar characters of the Indian astronomy: It is remarkable for its accuracy, and still more for its ingenuity and refinement; but is not reduced withal, to its ultimate simplicity.

20. THE tables of Tirvalore, however, though they differ in form very much from those formerly described, agree with them

* Mem. Acad. des Scien. *ibid.* p. 229. Ast. Ind. p. 84.

† M. LE GENTIL has given this table, Mem. Acad. *ibid.* p. 261.

them perfectly in many of their elements. They suppose the same length of the year, the same mean motions, and the same inequalities of the sun and moon, and they are adapted nearly to the same meridian*. But a circumstance in which they seem to differ materially from the rest is, the antiquity of the epoch from which they take their date, the year 3102 before the Christian era. We must, therefore, enquire, whether this epoch is real or fictitious, that is, whether it has been determined by actual observation, or has been calculated from the modern epochs of the other tables. For it may naturally be supposed, that the Brahmins, having made observations in later times, or having borrowed from the astronomical knowledge of other nations, have imagined to themselves a fictitious epoch, coinciding with the celebrated era of the Calyougham, to which, through

* THE accuracy of the geography of the Hindoos, is in no proportion to that of their astronomy, and, therefore, it is impossible that the identity of the meridians of their tables can be fully established. All that can be said, with certainty, is, that the difference between the meridians of the tables of Tirvalore and Siam is, at most, but inconsiderable, and may be only apparent, arising from an error in computing the difference of longitude between these places. The tables of Tirvalore are for Long. $79^{\circ}, 42'$; those of Siam for $82^{\circ}, 34'$; the difference is $2^{\circ}, 52'$, not more than may be ascribed to an error purely geographical.

As to the tables of Chirfnabouram, they contain a reduction, by which it appears, that the place where they are now used is $45'$ of a degree east of the meridian for which they were originally constructed. This makes the latter meridian agree tolerably with that of Cape Comorin, which is in Long. $77^{\circ}, 32', 30''$, and about half a degree west of Chirfnabouram. But this conclusion is uncertain; because, as M. BAILLY has remarked, the tables sent from Chirfnabouram, and understood by Father DU CHAMP to belong to that place, are not adapted to the latitude of it, but to one considerably greater, as appears from their rule for ascertaining the length of the day. (Astr. Ind. p. 33.)

THE characters, too, by which the Brahmins distinguish their first meridian, are not perfectly consistent with one another. Sometimes it is described as bisecting Ceylon; and at other times, as touching it on the west side, or even as being as far west as Cape Comorin. Lanka, which is said to be a point in it, is understood, by Fath. DU CHAMP, to be Ceylon. M. BAILLY thinks that it is the lake Lanka, the source of the Gogra, placed by M. RENNEL, as well as the middle of Ceylon, in Long. $80^{\circ}, 42'$; but, from a Hindoo map, in the Ayeen Akbery, vol. iii. p. 25. Lanka appears to be an island which marks the intersection of the first meridian of the map, nearly that of Cape Comorin, with the equator; and is probably one of the Maldivy islands. See also a note in the Ayeen Akbery, *ibid.* p. 36.

through vanity or superstition, they have referred the places of the heavenly bodies, and have only calculated what they pretend that their ancestors observed.

21. IN doing this, however, the Brahmins must have furnished us with means, almost infallible, of detecting their imposture. It is only for astronomy, in its most perfect state, to go back to the distance of forty-six centuries, and to ascertain the situation of the heavenly bodies at so remote a period. The modern astronomy of Europe, with all the accuracy that it derives from the telescope and the pendulum, could not venture on so difficult a task, were it not assisted by the theory of gravitation, and had not the integral calculus, after an hundred years of almost continual improvement, been able, at last, to determine the disturbances in our system, which arise from the action of the planets on one another.

UNLESS the corrections for these disturbances be taken into account, any system of astronomical tables, however accurate at the time of its formation, and however diligently copied from the heavens, will be found less exact for every instant, either before or after that time, and will continually diverge more and more from the truth, both for future and past ages. Indeed, this will happen, not only from the neglect of these corrections, but also from the small errors unavoidably committed, in determining the mean motions, which must accumulate with the time, and produce an effect that becomes every day more sensible, as we retire, on either side, from the instant of observation. For both these reasons, it may be established as a maxim, that, if there be given a system of astronomical tables, founded on observations of an unknown date, that date may be found, by taking the time when the tables represent the celestial motions most exactly.

HERE, therefore, we have a criterion, by which we are to judge of the pretensions of the Indian astronomy to so great antiquity. It is true, that, in applying it, we must suppose our
modern

modern astronomy, if not perfectly accurate, at least so exact as to represent the celestial motions, without any sensible error, even for a period more remote than the Calyougham; and this, considering the multitude of observations on which our astronomy is founded, the great antiquity of some of those observations, and the extreme accuracy of the rest, together with the assistance derived from the theory of physical causes, may surely be assumed as a very reasonable postulatam. We begin with the examination of the mean motions.

22. THE Brahmins place the beginning of their moveable zodiac, at the time of their epoch, 54° before the vernal equinox, or in the longitude of 10° , $6'$, according to our method of reckoning. Now, M. LE GENTIL brought with him a delineation of the Indian zodiac, from which the places of the stars in it may be ascertained with tolerable exactness *. In particular, it appears, that Aldebaran, or the first star of Taurus, is placed in the last degree of the fourth constellation, or 53° , $20'$, distant from the beginning of the zodiac. Aldebaran was therefore $40'$ before the point of the vernal equinox, according to the Indian astronomy, in the year 3102 before CHRIST. But the same star, by the best modern observations, was, in the year 1750, in longitude, 2° , $6'$, $17'$, $47''$; and had it gone forward, according to the present rate of the precession of the equinoxes, $50''\frac{1}{2}$ annually, it must have been, at the era of the Calyougham, 1° , $32'$, before the equinox. But this result is to be corrected, in consequence of the inequality in the precession, discovered by M. DE LA GRANGE †, by the addition of 1° , $45'$, $22''$, to the longitude of Aldebaran, which gives the longitude of that star $13'$ from the vernal equinox, at the time of the Calyougham, agreeing, within $53'$, with the determination of the Indian astronomy ‡.

VOL. II.

u

THIS

* Mem. Acad. Scien. 1772, II. P. 214. Aft. Ind. p. 129.

† Mem. Acad. de Berlin, 1782, p. 287. Aft. Ind. p. 144.

‡ Aft. Ind. p. 130.

THIS agreement is the more remarkable, that the Brahmins, by their own rules for computing the motion of the fixed stars, could not have assigned this place to Aldebaran for the beginning of the Calyougham, had they calculated it from a modern observation. For as they make the motion of the fixed stars too great by more than 3" annually, if they had calculated backward from 1491, they would have placed the fixed stars less advanced by 4° or 5°, at their ancient epoch, than they have actually done. This argument carries with it a great deal of force; and even were it the only one we had to produce, it would render it, in a high degree, probable, that the Indian zodiac was as old as the Calyougham.

23. LET us next compare the places of the sun and moon, for the beginning of the Calyougham, as deduced from the Indian and the modern astronomy. And, first, of the sun, though, for a reason that will immediately appear, it is not to be considered as leading to any thing conclusive. M. BAILLY, from a comparison of the tables of Tirvalore with those of Chirfnabouram, has determined the epoch of the former to answer to midnight, between the 17th and 18th* of February of the year 3102 before CHRIST, at which time the sun was just entering the moveable zodiac, and was therefore in longitude 10°, 6°. M. BAILLY also thinks it reasonable to suppose, that this was not the mean place of the sun, as the nature of astronomical tables require, but the true place, differing from the mean, by the equation to the sun's centre at that time†. This, it must be confessed, is the mark of greatest unskilfulness, that we meet with in the construction of these tables. Supposing it, however, to be the case, the mean place of the sun, at the time
of

* Aft. Ind. p. 110. The Brahmins, however, actually suppose the epoch to be 6 hours later, or at sunrise, on the same day. Their mistake is discovered, as has been said, by comparing the radical places in the different tables with one another.

† Aft. Ind. p. 83.

of the epoch, comes out $10^{\circ}, 3^{\circ}, 38', 13''$. Now, the mean longitude of the sun, from DE LA CAILLE's tables, for the same time, is $10^{\circ}, 1^{\circ}, 5', 57''$, supposing the precession of the equinoxes to have been uniformly at the rate it is now, that is, $50''\frac{1}{2}$ annually. But M. DE LA GRANGE has demonstrated, that the precession was less in former ages than in the present; and his formula gives $1^{\circ}, 45', 22''$, to be added, on that account, to the sun's longitude already found, which makes it $10^{\circ}, 2^{\circ}, 51', 19''$, not more than $47'$ from the radical place in the tables of Tirvalore. This agreement is near enough to afford a strong proof of the reality of the ancient epoch, if it were not for the difficulty that remains about considering the sun's place as the true, rather than the mean; and, for that reason, I am unwilling that any stress should be laid upon this argument. The place of the moon is not liable to the same objection.

24. THE moon's mean place, for the beginning of the Calyougham, (that is, for midnight between the 17th and 18th of February 3102, A. C. at Benares), calculated from MAYER's tables, on the supposition that her motion has always been at the same rate as at the beginning of the present century, is $10^{\circ}, 0^{\circ}, 51', 16''$ *. But, according to the same astronomer, the moon is subject to a small, but uniform acceleration, such, that her angular motion, in any one age, is $9''$ greater than in the preceding, which, in an interval of 4801 years, must have amounted to $5^{\circ}, 45', 44''$. This must be added to the preceding, to give the real mean place of the moon, at the astronomical epoch of the Calyougham, which is therefore $10^{\circ}, 6^{\circ}, 37'$. Now, the same, by the tables of Tirvalore, is $10^{\circ}, 6^{\circ}, 0'$; the difference is less than two-thirds of a degree, which, for so remote a period, and considering the acceleration of the moon's motion, for which no allowance

u 2 could

* Aft. Ind. p. 142, &c. The first meridian is supposed to pass through Benares; but even if it be supposed 3° farther west, the difference, which is here $37'$, will be only increased to $42'$.

could be made in an Indian calculation, is a degree of accuracy that nothing but actual observation could have produced.

25. To confirm this conclusion, M. BAILLY computes the place of the moon for the same epoch, by all the tables to which the Indian astronomers can be supposed to have ever had access*. He begins with the tables of PTOLEMY; and if, by help of them, we go back from the era of NABONASSAR, to the epoch of the Calyougham, taking into account the comparative length of the Egyptian and Indian years, together with the difference of meridians between Alexandria and Tirvalore, we shall find the longitude of the sun $10^{\circ}, 21', 15''$ greater, and that of the moon $11^{\circ}, 52', 7''$ greater than has just been found from the Indian tables†. At the same time that this shews, how difficult it is to go back, even for a less period than that of 3000 years, in an astronomical computation, it affords a proof, altogether demonstrative, that the Indian astronomy is not derived from that of PTOLEMY.

THE tables of ULUGH BEIG are more accurate than those of the Egyptian astronomer. They were constructed in a country not far from India, and but a few years earlier than 1491, the epoch of the tables of Chirsnabouram. Their date is July 4. at noon, 1437, at Samarcand; and yet they do not agree with the Indian tables, even at the above mentioned epoch of 1491‡. But, for the year 3102 before CHRIST, their difference from them, in the place of the sun, is $1^{\circ}, 30'$, and in that of the moon 6° ; which, though much less than the former differences, are sufficient to show, that the tables of India are not borrowed from those of Tartary.

THE Arabians employed in their tables the mean motions of PTOLEMY; the Persians did the same, both in the more ancient tables of CHRYSOCOCCA, and the later ones of NASSIREDDIN§. It is

* Aft. Ind. p. 114.

† Ibid. p. 115.

‡ Ibid. p. 117.

§ Ibid. p. 118.

is therefore certain, that the astronomy of the Brahmins is neither derived from that of the Greeks, the Arabians, the Persians or the Tartars. This appeared so clear to CASSINI, though he had only examined the tables of Siam, and knew nothing of many of the great points which distinguish the Indian astronomy from that of all other nations, that he gives it as his opinion, that these tables are neither derived from the Persian astronomy of CHRYSOCOCCA, nor from the Greek astronomy of PROLEMY; the places they give at their epoch to the apogee of the sun, and of the moon, and their equation for the sun's centre, being very different from both*.

26. BUT, to return to what respects the moon's acceleration; it is plain, that tables, as ancient as those of Tirvalore pretend to be, ought to make the mean motion of that planet much slower than it is at present. They do accordingly suppose, in the rule for computing the place of the moon, already described, that her motion for 4383 years, 94 days, reckoned in the moveable zodiac from the epoch of the Calyougham, is $7^{\circ}, 2'$; $0', 7''$, or $9^{\circ}, 7', 45'', 1''$, when referred to the fixed point of the vernal equinox. Now, the mean motion for the same interval, taken from the tables of MAYER, is greater than this, by $2^{\circ}, 42', 4''$ †, which, though conformable, in general, to the notion of the moon's motion having been accelerated, falls, it must be confessed, greatly short of the quantity which MAYER has assigned to that acceleration. This, however, is not true of all the tables; for the moon's motion in 4383 years, 94 days, taken from those of Chirsnabouram, is $3^{\circ}, 2', 10''$ less than in the tables of Tirvalore ‡; from which it is reasonable to conclude, with M. BAILLY, that the former are, in reality, more ancient than the latter, though they do not profess to be so: and hence, also, the tables of Chirsnabouram make

* Mem. Acad. Scien. tom. 8. p. 286.

† Ast. Ind. p. 145.

‡ Ibid. p. 126.

make the moon's motion less than *MAYER*'s, for the above mentioned interval, by 5° , $44'$, $14''$, which therefore is, according to them, the quantity of the acceleration.

27. Now, it is worthy of remark, that if the same be computed on *MAYER*'s principles, that is, if we calculate how much the angular motion of the moon for 4383 years, 94 days, dated from the beginning of the Calyougham, must have been less than if her velocity had been all that time uniform, and the same as in the present century, we shall find it to be 5° . $43'$, $7''$, an arch which is only $1'$, $7''$, less than the former. The tables of *Christnabouram*, therefore, agree with those of *MAYER*, when corrected by the acceleration within $1'$, $7''$, and that for a period of more than four thousand years. From this remarkable coincidence, we may conclude, with the highest probability, that at least one set of the observations, on which those tables are founded, is not less ancient than the Calyougham; and though the possibility of their being some ages later than that epoch, is not absolutely excluded, yet it may, by strict mathematical reasoning, be inferred, that they cannot have been later than 2000 years before the Christian era*.

28. THIS

* THE reasoning here referred to is the following: As the mean motions, in all astronomical tables, are determined by the comparison of observations made at a great distance of time from one another; if x be the number of centuries between the beginning of the present, and the date of the more ancient observations, from which the moon's mean motion in the tables of *Christnabouram* is deduced; and if y denote the same for the more modern observations: then the quantity by which the moon's motion, during the interval $x-y$, falls short of *MAYER*'s, for the same interval, is $(x^2-y^2)9'$.

IF, therefore, m be the motion of the moon for a century in the last mentioned tables, $m(x-y)-9'(x^2-y^2)$ will be the mean motion for the interval $x-y$ in the tables of *Christnabouram*. If, then, a be any other interval, as that of 43.83 centuries, the mean motion assigned to it, in these last tables, by the rule of proportion, will be $\frac{ma(x-y)-9'a(x^2-y^2)}{x-y} = ma-9a(x+y)$. Let this motion, actually taken from the ta-

bles

28. THIS last is one of the few coincidences between the astronomy of India and of Europe, which their ingenious historian has left for others to observe. Indeed, since he wrote, every argument, founded on the moon's acceleration, has become more worthy of attention, and more conclusive. For that acceleration is no longer a mere empirical equation, introduced to reconcile the ancient observations with the modern, nor a fact that can only be accounted for by hypothetical causes, such as the resistance of the ether, or the time necessary for the transmission of gravity; it is a phenomenon, which M. DE LA PLACE has *, with great ability, deduced from the principle of universal gravitation, and shewn to be necessarily connected with the changes in the eccentricity of the earth's orbit, discovered by M. DE LA GRANGE; so that the acceleration of the moon is indirectly produced by the action of the planets, which alternately increasing and diminishing the said eccentricity, subjects the moon to different degrees of that force by which the sun disturbs the time of her revolution round the earth. It is therefore a periodical inequality, by which the moon's motion, in the course of ages, will be as much retarded as accelerated; but its changes are so slow, that her motion has been constantly accelerated, even for a longer period than that to which the observations of India extend.

A

bles be $= na$, then $ma - na = 9a(x+y)$, or $x+y = \frac{m-n}{g} = 52.19$, in the present case. It is certain, therefore, that whatever supposition be made with respect to the interval between x and y , their sum must always be the same, and must amount to 5219 years. But that, that interval may be long enough to give the mean motions with exactness, it can scarcely be supposed less than 2000 years; and, in that case, $x = 3609$ years, which therefore is its least value. But if 3609 be reckoned back from 1700, it goes up to 1909 years before CHRIST, nearly, as has been said.

It must be remembered, that what is here investigated is the limit, or the most modern date possible to be assigned to the observations in question. The supposition that $x-y = a$, is the most probable of all, and it gives $x = 4801$, which corresponds to the beginning of the Calyougham.

* Mem. Acad. des Scien. 1786, p. 235, &c.

A FORMULA for computing the quantity of this inequality, has been given by M. DE LA PLACE, which, though only an approximation, being derived from theory, is more accurate than that which MAYER deduced entirely from observation * ; and if it be taken instead of MAYER's, which last, on account of its simplicity, I have employed in the preceding calculations, it will give a quantity somewhat different, though not such as to affect the general result. It makes the acceleration for 4383 years, dated from the beginning of the Calyougham, to be greater by $17', 39''$, than was found from MAYER's rule, and greater consequently by $16', 32''$, than was deduced from the tables of Chirfnabouram. It is plain, that this coincidence is still near enough to leave the argument, that is founded on it, in possession of all its force, and to afford a strong confirmation of the accuracy of the theory, and the authenticity of the tables.

THAT observations made in India, when all Europe was barbarous or uninhabited, and investigations into the most subtle effects of gravitation made in Europe, near five thousand years afterwards, should thus come in mutual support of one another, is perhaps the most striking example of the progress and vicissitude of science, which the history of mankind has yet exhibited.

29. THIS, however, is not the only instance of the same kind that will occur, if, from examining the radical places and mean motions in the Indian astronomy, we proceed to consider some other of its elements, such as, the length of the year, the inequality of the sun's motion, and the obliquity of the ecliptic, and compare them with the conclusions deduced, from the theory of gravity, by M. DE LA GRANGE. To that geometer, physical astronomy is indebted for one of the most beautiful of its discoveries, *viz.* That all the variations in our system are periodical; so that though every thing, almost without exception,

* Mem. Acad. des Scien. 1786, p. 260.

tion, be subject to change, it will, after a certain interval, return to the same state in which it is at present, and leave no room for the introduction of disorder, or of any irregularity that might constantly increase. Many of these periods, however, are of vast duration. A great number of ages, for instance, must elapse before the year be again exactly of the same length, or the sun's equation of the same magnitude as at present*. An astronomy, therefore, which professes to be so ancient as the Indian, ought to differ considerably from ours in many of its elements. If indeed these differences are irregular, they are the effects of chance, and must be accounted errors; but if they observe the laws, which theory informs us that the variations in our system do actually observe, they must be held as the most undoubted marks of authenticity. We are to examine, as M. BAILLY has done, which of these takes place in the case before us †.

30. THE tables of Tirvalore, which, as we have seen, refer their date to the beginning of the Calyougham, make the syderial year to consist of $365^d, 6^h, 12', 30''$; and therefore the tropical of $365^d, 5^h, 50', 35''$, which is $1', 46''$, longer than that of DE LA CAILLE ‡. Now, the tropical year was in reality longer at that time than it is at present; for though the syderial year, or the time which the earth takes to return from one point of space to the same point again, is always of the same magnitude, yet the tropical year being affected by the precession of the equinoxes, is variable by a small quantity, which never can exceed $3', 40''$, and which is subject to flow, and unequal alternations of diminution and increase. A theorem, expressing the law and the quantity of this variation, has been investigated by M. DE LA GRANGE, in the excellent Me-

VOL. II.

✱

moir

* Mem. de l'Acad. de Berlin, 1782, p. 170, &c.

† Ast. Ind. p. 160, &c.

‡ Supra, § 18. and 10.

moir already mentioned *; and it makes the year 3102 before CHRIST, $40''\frac{1}{2}$ longer than the year at the beginning of the present century †. The year in the tables of Tirvalore is therefore too great by $1'$, $5''\frac{1}{2}$.

31. BUT the determination of the year is always from a comparison of observations made at a considerable interval from one another; and, even to produce a degree of accuracy much less than what we see belongs to the tables of Tirvalore, that interval must have been of several ages. Now, says M. BAILLY, if we suppose these observations to have been made in that period of 2400 years, immediately preceding the Calyougham, to which the Brahmins often refer; and if we also suppose the inequality of the precession of the equinoxes, to increase as we go back, in proportion to the square of the times, we shall find, that, at the middle of this period, or 1200 years before the beginning of the Calyougham, the length of the year was 365^d , 5^h , $50'$, $41''$, almost precisely as in the tables of Tirvalore. And hence it is natural to conclude, that this determination of the solar year is as ancient as the year 1200 before the Calyougham, or 4300 before the Christian era ‡.

32. IN this reasoning, however, it seems impossible to acquiesce; and M. BAILLY himself does not appear to have relied on it with much confidence ||. We are not at liberty to suppose, that the precession of the equinoxes increases in the ratio above mentioned, or, which is the same, that the equinoctial points go back with a motion equably retarded. If, by M. DE GRANGE's formula, we trace back, step by step, the variation of the solar year, we shall find, that about the beginning of the Calyougham, it had nearly attained the extreme point of
one

* Mem. Acad. Berlin, 1782. p. 289.

† Ast. Ind. p. 160.

‡ Ibid. p. 161.

|| HE says, " Sans doute il ne peut résulter de ce calcul qu'un aperçu."

one of those vibrations, which many centuries are required to complete ; and that the year was then longer than it has ever been since, or than it had been for many ages before. It was $40''\frac{1}{2}$ longer than it is at present ; but, at the year 5500 before CHRIST, it was only $29''$ longer than at present, instead of $2'$, $50''$, which is the result of M. BAILLY's supposition. During all the intervening period of 2400 years, the variation of the year was between these two quantities ; and we cannot therefore, by any admissible supposition, reduce the error of the tables to less than $1'$, $5''$. The smallness of this error, though extremely favourable to the antiquity, as well as the accuracy of the Indian astronomy, is a circumstance from which a more precise conclusion can hardly be deduced.

33. THE equation of the sun's centre is an element in the Indian astronomy, which has a more unequivocal appearance of belonging to an earlier period than the Calyougham. The maximum of that equation is fixed, in these tables, at 2° , $10'$, $32''$. It is at present, according to M. DE LA CAILLE, 1° , $55'\frac{1}{2}$, that is, $15'$ less than with the Brahmins. Now, M. DE LA GRANGE has shewn, that the sun's equation, together with the eccentricity of the earth's orbit, on which it depends, is subject to alternate diminution and increase, and accordingly has been diminishing for many ages. In the year 3102 before our era, that equation was 2° , $6'$, $28''\frac{1}{2}$; less, only by $4'$, than in the tables of the Brahmins. But if we suppose the Indian astronomy to be founded on observations that preceded the Calyougham, the determination of this equation will be found to be still more exact. Twelve hundred years before the commencement of that period, or about 4300 years before our era, it appears, by computing from M. DE LA GRANGE's formula, that the equation of the sun's centre was actually 2° , $8'$, $16''$; so that if the Indian astronomy be as old as that period, its error with respect to this equation is but of $2' *$.

* Astr. Ind. p. 163.

34. THE obliquity of the ecliptic is another element in which the Indian astronomy and the European do not agree, but where their difference is exactly such as the high antiquity of the former is found to require. The Brahmins make the obliquity of the ecliptic 24° . Now, M. DE LA GRANGE's formula for the variation of the obliquity*, gives $22'$, $32''$, to be added to its obliquity in 1700, that is, to 23° , $28'$, $41''$, in order to have that which took place in the year 3102 before our era. This gives us 23° , $51'$, $13''$, which is $8'$, $47''$, short of the determination of the Indian astronomers. But if we suppose, as in the case of the sun's equation, that the observations on which this determination is founded, were made 1200 years before the Calyougham, we shall find that the obliquity of the ecliptic was 23° , $57'$, $45''$, and that the error of the tables did not much exceed $2'$ †.

35. THUS, do the measures which the Brahmins assign to these three quantities, the length of the tropical year, the equation of the sun's centre, and the obliquity of the ecliptic, all agree in referring the epoch of their determination to the year 3102 before our era, or to a period still more ancient. This coincidence in three elements, altogether independent of one another, cannot be the effect of chance. The difference, with respect to each of them, between their astronomy and ours, might singly perhaps be ascribed to inaccuracy; but that three errors, which chance had introduced, should be all of such magnitudes, as to suit exactly the same hypothesis concerning their origin, is hardly to be conceived. Yet there is no other alternative, but to admit this very improbable supposition, or to acknowledge that the Indian astronomy is as ancient as one, or other of the periods above mentioned.

36. THIS conclusion would receive great additional confirmation, could we follow M. BAILLY in his analysis of the astronomy

* Mem. Acad. Berlin, 1782, p. 287.

† Ast. Ind. p. 165.

onomy of the planets, contained in the tables of Chrisna-bouram*; but the length to which this *paper* is already extended, will allow only a few of the most remarkable particulars to be selected.

IN these tables, which are for the epoch 1491, the mean motions are given with considerable accuracy, but without an appearance of being taken from PTOLEMY, or any of the astronomers already mentioned. Two inequalities, called the *schigram* and the *manda*, are also distinguished in each of the planets, both superior and inferior†. The first of these is the same with that which we call the parallax of the earth's orbit, or the apparent inequality of a planet, which arises not from its own motion, but from that of the observer; but whether it is ascribed, in the Indian astronomy, to its true cause, or to the motion of the planet in an epicycle, is a question about which the tables give no direct information. The magnitude, however, of this equation is assigned, for each of the planets, with no small exactness, and is varied, in the different points of its orbit, by a law which approaches very near to the truth.

THE other inequality coincides with that of the planet's centre, or that which arises from the eccentricity of its orbit, and it is given near the truth for all the planets, except Mercury, by which, as is no wonder, the first astronomers were, every where, greatly deceived. Of this inequality, it is supposed, just as in the cases of the sun and moon, that it is always as the sine of the planet's distance from the point of its slowest motion, or from what we call its aphelion, and is consequently greatest at 90° from that point.

It were to be wished that we knew the etymology of the names which are given to these inequalities, as it might explain the theory which guided the authors of the tables. The titles of our astronomical tables, the terms *aphelion*, *heliocentric*

or

* Ast. Ind. p. 173, &c.

† Ibid. p. 177.

or *geocentric place*, &c. would discover the leading ideas of the Copernican system, were no other description of it preserved.

37. IN the manner of applying these two inequalities, to correct the mean place of a planet, the rules of this astronomy are altogether singular. In the case of a superior planet, they do not make use of the mean anomaly, as the argument for finding out the equation *manda*, but of that anomaly, when corrected first by half the equation *schigram*, and afterwards by half the equation *manda* *. By the equation of the centre, obtained with this argument, the mean longitude of the planet is corrected, and its true heliocentric place consequently found, to which there is again applied the parallax of the annual orbit, that the geocentric place may be obtained. The only difficulty here, is in the method of taking out from the tables the equation to the centre. It is evidently meant for avoiding some inaccuracy, which was apprehended from a more direct method of calculation, but of which, even after the ingenious remarks of M. BAILLY, it seems impossible to give any clear and satisfactory account.

38. THE manner of calculating the places of the inferior planets has a great resemblance to the former ; with this difference, however, that the equation *manda*, or of the centre, is applied to correct, not the mean place of the planet, but the mean place of the sun ; and to this last, when so corrected, is applied the equation *schigram*, which involves the planet's elongation from the sun, and gives its geocentric place †. This necessarily implies, that the centre, about which the inferior planets revolve, has the same apparent mean motion with the sun : but whether it be a point really different from the sun, or the same ; and, if the same, whether it be in motion or at rest, are left entirely undetermined, and we know not, whether, in the astronomy of India, we have here discovered a resemblance

* Ast. Ind. p. 194.

† Ibid. p. 199, &c.

blance to the Ptolemaic, the Tychonic^{*}, or the Copernican system.

39. THESE tables, though their radical places are for the year 1491 of our era, have an obvious reference to the great epoch of the Calyougham. For if we calculate the places of the planets from them, for the beginning of the astronomical year, at that epoch, we find them all in conjunction with the sun in the beginning of the moveable zodiac, their common longitude being $10^s, 6^{\circ}$ *. According to our tables, there was, at that time, a conjunction of all the planets, except Venus, with the sun ; but they were, by no means, so near to one another as the Indian astronomy represents. It is true, that the exact time of a conjunction cannot be determined by direct observation : but this does not amount to an entire vindication of the tables ; and there is reason to suspect, that some superstitious notions, concerning the beginning of the Calyougham, and the signs by which nature must have distinguished so great an epoch, has, in this instance at least, perverted the astronomy of the Brahmins. There are, however, some coincidences between this part of their astronomy, and the theory of gravity, which must not be forgotten.

40. THE first of these respects the aphelion of Jupiter, which, in the tables, is supposed to have a retrograde motion of 15° in 200,000 years †, and to have been, at the epoch of 1491, in longitude $5^s, 21^{\circ}, 40', 20''$, from the beginning of the zodiac. It follows, therefore, that in the year 3102 before CHRIST, the longitude of Jupiter's aphelion was $3^s, 27^{\circ}, 6'$, reckoned from the equinox. Now, the same, computed from M. DE LA LANDE's tables, is only $3^s, 16^{\circ}, 48', 58''$; so that there would seem to be an error of more than 10° in the tables of the Brahmins. But, if it be considered, that Jupiter's orbit

is

* Aft. Ind. p. 181.

† Ibid. p. 184. § 13.

is subject to great disturbances, from the action of Saturn, which M. DE LA LANDE does not profess to have taken into account, we will be inclined to appeal once more to M. DE LA GRANGE's formulas, before we pass sentence against the Indian astronomy *.

FROM one of these formulas, we find, that the true place of the aphelion of Jupiter, at the time above mentioned, was $3^{\circ}, 26', 50'', 40''$, which is but $10', 40''$, different from the tables of Chrisnabouram. The French and Indian tables are therefore both of them exact, and only differ because they are adapted to ages near five thousand years distant from one another.

41. THE equation of Saturn's centre is an instance of the same kind. That equation, at present, is, according to M. DE LA LANDE, $6^{\circ}, 23', 19''$; and hence, by means of one of the formulas above mentioned, M. BAILLY calculates, that, 3102 years before CHRIST, it was $7^{\circ}, 41', 22''$ †. The tables of the Brahmins make it $7^{\circ}, 39', 44''$, which is less only by $1', 38''$, than the preceding equation, though greater than that of the present century by $1^{\circ}, 16', 25''$.

42. M. BAILLY remarks, that the equations for the other planets are not given with equal accuracy, and afford no more such instances as the former. But it is curious to observe, that new researches into the effects of gravitation, have discovered new coincidences of the same kind; and that the two great geometers, who have shared between them the glory of perfecting the *theory of disturbing forces*, have each contributed his part to establish the antiquity of the Indian astronomy. Since the publication of M. BAILLY's work, two other instances of an exact agreement, between the elements of these tables, and the conclusions deduced from the theory of gravity, have been observed, and communicated to him by M. DE LA PLACE, in a letter, inserted in the *Journal des Savans*.

IN

* Mem. Acad. Berlin. 1782, p. 246. Ast. Ind. p. 186.

† Ast. Ind. p. 188.

IN seeking for the cause of the secular equations, which modern astronomers have found it necessary to apply to the mean motion of Jupiter and Saturn, M. DE LA PLACE has discovered, that there are inequalities belonging to both these planets, arising from their mutual action on one another, which have long periods, one of them no less than 877 years; so that the mean motion must appear different, if it be determined from observations made in different parts of those periods. "Now," I find," says he, "by my theory, that at the Indian epoch of 3102 years before CHRIST, the apparent and annual mean motion of Saturn was 12° , $13'$, $14''$, and the Indian tables make it 12° , $13'$, $13''$."

"In like manner, I find, that the annual and apparent mean motion of Jupiter at that epoch was 30° , $20'$, $42''$, precisely as in the Indian astronomy *."

43. THUS have we enumerated no less than nine astronomical elements †, to which the tables of India assign such values as do, by no means, belong to them in these later ages, but such as the theory of gravity proves to have belonged to them three thousand years before the Christian era. At that time, therefore, or in the ages preceding it, the observations must have been made from which these elements were deduced. For it is abundantly evident, that the Brahmins of later times, however willing they might be to adapt their tables to so remarkable an epoch as the Calyougham, could never think of doing so, by substituting, instead of quantities which they had observed, others which they had no reason to believe had ever existed. The elements in question are precisely what these

VOL. II.

y

astronomers

* *Esprit des Journeaux*, Nov. 1787. p. 80.

† THE inequality of the precession of the equinoxes, (§ 22.); the acceleration of the moon; the length of the solar year; the equation of the sun's centre; the obliquity of the ecliptic; the place of Jupiter's aphelion; the equation of Saturn's centre; and the inequalities in the mean motion of both these planets.

astronomers must have supposed invariable, and of which, had they supposed them to change, they had no rules to go by for ascertaining the variations; since, to the discovery of these rules is required, not only all the perfection to which astronomy is, at this day, brought in Europe, but all that which the sciences of motion and of extension have likewise attained. It is no less clear, that these coincidences are not the work of accident; for it will scarcely be supposed that chance has adjusted the errors of the Indian astronomy with such singular felicity, that observers, who could not discover the true state of the heavens, at the age in which they lived, have succeeded in describing one which took place several thousand years before they were born.

44. THE argument, however, which regards the originality of these tables, is, in some measure, incomplete, till we have considered the geometrical principles which have been employed in their construction. For it is not impossible, that when seen connected by those principles, and united into general theorems, they may be found to have relations to the Greek astronomy, which did not appear, when the parts were examined singly. On this subject, therefore, I am now to offer a few observations.

45. THE rules by which the phenomena of eclipses are deduced from the places of the sun and moon, have the most immediate reference to geometry; and of these rules, as found among the Brahmins of Tirvalore, M. LE GENTIL has given a full account, in the Memoir that has been so often quoted. We have also an account of the method of calculation used at Chrisnabouram by Father DU CHAMP*.

IT is a necessary preparation, in both of these, to find the time of the sun's continuance above the horizon, at the place and the day for which the calculation of an eclipse is made, and the rule by which the Brahmins resolve this problem, is extremely simple and

* Aft. Ind. p. 355, &c.

and ingenious. At the place for which they calculate, they observe the shadow of a gnomon on the day of the equinox, at noon, when the sun, as they express it, is in the middle of the world. The height of the gnomon is divided into 720 equal parts, in which parts the length of the shadow is also measured. One third of this measure is the number of minutes by which the day, at the end of the first month after the equinox, exceeds twelve hours; four-fifths of this excess is the increase of the day during the second month; and one third of it is the increase of the day, during the third month*.

46. It is plain, that this rule involves the supposition, that, when the sun's declination is given, the same ratio every where exists between the arch which measures the increase of the day at any place, and the tangent of the latitude; for that tangent is the quotient which arises from dividing the length of the shadow by the height of the gnomon. Now, this is not strictly true; for such a ratio only subsists between the chord of the arch, and the tangent above mentioned. The rule is, therefore, but an approximation to the truth, as it necessarily supposes the arch in question to be so small as to coincide nearly with its chord. This supposition holds only of places in low latitudes; and the rule which is founded on it, though it may safely be applied in countries between the tropics, in those that are more remote from the equator, would lead into errors too considerable to escape observation †.

y 2

As

* Mem. Acad. des Scien. II. P. 175.

† To judge of the accuracy of this approximation, suppose O to be the obliquity of the ecliptic, and x the excess of the semidiurnal arch, on the longest day, above an arch of 90° , then $\sin. x = \tan. O \times \tan. lat.$ But if G be the height of a gnomon, and S the length of its shadow on the equinoctial day, $\frac{S}{G} = \tan. lat.$ and $\sin. x = \tan. O \times \frac{S}{G}$.

Therefore $x = \tan. O \times \frac{S}{G} + \frac{\tan. O^3 \times S^3}{6G^3} + \frac{\tan. O^5 \times S^5}{24G^5} + \&c.$ or in minutes of
time,

As some of the former rules, therefore, have served to fix the time, so does this, in some measure, to ascertain the place of its invention. It is the simplification of a general rule, adapted to the circumstances of the torrid zone, and suggested to the astronomers of Hindostan by their peculiar situation. It implies the knowledge of the circles of the sphere, and of spherical trigonometry, and perhaps argues a greater progress in mathematical reasoning, than a theorem that was perfectly accurate would have done. The first geometers must naturally have dreaded nothing so much as any abatement in the rigour of their demonstrations, because they would see no limits to the error and uncertainty, in which they might, by that means, be involved. It was long before the mathematicians of Greece understood how to set bounds to such errors, and to ascertain their utmost extent, whether on the side of excess or defect; in this art, they appear to have received the first lessons so late as the age of ARCHIMEDES.

47. THE

time, reckoned after the Indian manner, $x = 572.957 \left(\tan.O \times \frac{S}{G} + \tan.O^3 \times \right.$

$$\left. \frac{S^3}{6G^3} + \&c. \right)$$

If $O = 24^\circ$, then $\tan.O = .4452$, and the first term of this formula gives $x = 572.957 \times \frac{.4452S}{G} = \frac{255S}{G}$, which is the same with the rule of the Brahmins.

For that rule, reduced into a formula, is $2x = \frac{720S}{G} \left(\frac{1}{3} + \frac{4}{15} + \frac{1}{9} \right) =$

$$\frac{512S}{G}, \text{ or } x = \frac{256S}{G}.$$

THEY have therefore computed the coefficient of $\frac{S}{G}$ with sufficient accuracy; the error produced by the omission of the rest of the terms of the series will not exceed $1'$, even at the tropics, but, beyond them, it increases fast, and, in the latitude of 45° , would amount to $8'$.

47. THE Brahmins having thus obtained the variations of the length of the day, at any place, or what we call the ascensional differences, apply them likewise to another purpose. As they find it necessary to know the point of the ecliptic, which is on the horizon, at the time when an eclipse happens, they have calculated a table of the right ascensions of the points of the ecliptic in time, to which they apply the ascensional differences for the place in question, in order to have the time which each of the signs takes to descend below the horizon of that place *. This is exactly the method, as is well known, which the most skilful astronomer, in like circumstances, would pursue. Their table of the differences of right ascension is but for a few points in the ecliptic, *viz.* the beginning of each sign, and is only carried to minutes of time, or tenths of a degree. It is calculated, however, so far as it goes, with perfect accuracy, and it supposes the obliquity of the ecliptic, as before, to be twenty-four degrees.

SUCH calculations could not be made without spherical trigonometry, or some method equivalent to it. If, indeed, we would allow the least skill possible to the authors of these tables, we may suppose, that the arches were measured on the circles of a large globe, or armillary sphere, such as we know to have been one of the first instruments of the Egyptian and Greek astronomers. But there are some of the tables where the arches are put down true to seconds, a degree of accuracy which a mechanical method can scarcely have afforded.

48. IN another part of the calculation of eclipses, a direct application is made of one of the most remarkable propositions in geometry. In order to have the semiduration of a solar eclipse, they subtract from the square of the sum of the semidiameters of the sun and moon, the square of a certain line, which is a perpendicular from the centre of the sun on the path of the moon ; and from the remainder, they extract the

* Acad. des Scien. 1772, II. P. 205.

the square root, which is the measure of the femiduration *. The same thing is practised in lunar eclipses †. These operations are all founded on a very distinct conception of what happens in the case of an eclipse, and on the knowledge of this theorem, that, in a right-angled triangle, the square on the hypotenuse is equal to the squares on the other two sides. It is curious to find the theorem of PYTHAGORAS in India, where, for aught we know, it may have been discovered, and from whence that philosopher may have derived some of the solid, as well as the visionary speculations, with which he delighted to instruct or amuse his disciples.

49. WE have mentioned the use that is made of the femidiameters of the sun and moon in these calculations, and the method of ascertaining them, is deserving of attention. For the sun's apparent diameter, they take four-ninths of his diurnal motion, and for the moon's diameter, one twenty-fifth of her diurnal motion. In an eclipse, they suppose the section of the shadow of the earth, at the distance of the moon, to have a diameter five times that of the moon; and in all this, there is considerable accuracy, as well as great simplicity. The apparent diameters of the sun and moon, increase and diminish with their angular velocities; and though there be a mistake in supposing, that they do so exactly in the same proportion, it is one which, without telescopes and micrometers, cannot easily be observed. The section of the earth's shadow, likewise, if the sun's apparent diameter be given, increases as the moon's increases, or as her distance from the earth diminishes, and nearly enough in the same ratio to justify the rule which is here laid down.

50. THE historian of the Academy of Sciences, in giving an account of M. LE GENTIL's Memoir, has justly observed, that
the

* Mem. Acad. des Scien. 1772, II. P. 259.

† Ibid. 241.

the rule described in it, for finding the difference between the true and apparent conjunction, at the time of a solar eclipse, contains the calculation of the moon's parallax, but substitutes the parallax in right ascension for the parallax in longitude *; an error which the authors of this astronomy would probably have avoided, had they derived their knowledge from the writings of PTOLEMY. From this supposed parallax in longitude, they next derive the parallax in latitude, where we may observe an application of the doctrine of similar triangles; for they suppose the first of these to be to the last in the constant ratio of 25 to 2, or nearly as the radius to the tangent of the inclination of the moon's orbit to the plane of the ecliptic. We have here, therefore, the application of another geometrical theorem, and that too proceeding on the supposition, that a small portion of the sphere, on each side of the point which the sun occupies at the middle of the eclipse, may be held to coincide with a plane touching it in that point.

51. THE result which the Brahmins thus obtain will be allowed to have great accuracy, if it be considered how simple their rules are, and how long it must be since their tables were corrected by observations. In two eclipses of the moon, calculated in India by their method, and likewise observed there by M. LE GENTIL, the error, in neither case, exceeded 23' of time, (corresponding to one of 13' of a degree, in the place of the moon); and in the duration and magnitude of the eclipse, their calculation came still nearer to the truth †.

52. SINCE

* Hist. Acad. II. P. 109. Ibid. Mem. 253,—256.

† In the language, however, of their rules, we may trace some marks of a fabulous and ignorant age, from which indeed even the astronomy of Europe is not altogether free. The place of the moon's ascending node, is with them *the place of the Dragon* or *the Serpent*; the moon's distance from the node, is literally translated by M. LE GENTIL,

52. SINCE an inequality was first observed in the motions of the sun or moon, the discovery of the law which it follows, and the method of determining the quantity of it, in the different points of their orbits, has been a problem of the greatest importance ; and it is curious to inquire, in what manner the astronomers of India have proceeded to resolve it. For this purpose, we must examine the tables of the *chaiaa*, or equations of the centre for the sun and moon, and of the *manda*, or equations of the centre for the planets. With respect to the first, as contained in the tables of Siam, M. CASSINI observed, that the equations followed the ratio of the sines of the mean distances from the apogee ; but as they were calculated only for a few points of the orbit, it could not be known with what degree of exactness this law was observed. Here, however, the tables of Chrisnabouram remove the uncertainty, as they give the equation of the centre for every degree of the mean motion, and make it nearly as the sine of the distance from the apogee.

THEY do so, however, only nearly ; and it will be found on trial, that there is, in the numbers of the table, a small, but regular variation from this law, which is greatest when the argument is 30° , though even there it does not amount to a minute. The sun's equation, for instance, which, when greatest, or when the argument is 90° , is, by these tables, $2^\circ, 10', 32''$, should be, when the argument is 30° , just the half of this, or $1^\circ, 5', 16''$, did the numbers in the table follow exactly the ratio

la lune offensée du dragon. Whether it be that we have borrowed these absurdities from India, along with astrology, or if the popular theory of eclipses has, at first, been every where the same, the moon's node is also known with us by the name of the *cauda draconis*. In general, however, the signification of the terms in these rules, so far as we know it, is more rational. In one of them we may remark considerable refinement ; *ayanangsam*, which is the name for the reduction made on the sun's longitude, on account of the precession of the equinoxes, is compounded from *ayanam*, a *course*, and *angsam*, an *atom*. Mem. Acad. II. P. 251. The equinox is almost the only point not distinguished by a visible object, of which the *course* or motion is computed in this astronomy.

ratio of the fines of the argument. It is, however, $1^{\circ}, 6', 3''$; and this excess of $47''$ cannot have arisen from any mistake about the ratio of the fine of 30° to that of 90° , which is shewn to be that of 1 to 2, by a proposition in geometry * much too simple to have been unknown to the authors of these tables. The rule, therefore, of the equations, being proportional exactly to the fines of the argument, is not what was followed, or intended to be followed, in the calculation of them. The differences, also, between the numbers computed by that rule, and those in the tables, are perfectly regular, decreasing from the point of 30° , both ways toward the beginning and end of the quadrant, where they vanish altogether.

THESE observations apply also to the tables of Narfapur †, and to the moon's equations, as well as to the sun's, with a circumstance, however, which is not easily accounted for, viz. that the differences between the numbers calculated by M. CASSINI's rule, and those in the tables, are not greater in the case of the moon than of the sun, though the equation of the latter be more than double that of the former. They apply also to the tables *manda* of the planets, where the equations are greater than the ratio of the fines of their arguments requires, the excess being greatest at 30° , and amounting to some minutes in the equations of Saturn, Jupiter and Mars, in which last it is greatest of all.

53. THOUGH, for these reasons, it is plain, that the rule of M. CASSINI is not the same with that of the Brahmins, it certainly includes the greater part of it; and if the latter, whatever it may have been, were expressed in a series, according to the methods of the modern analysis, the former would be the first term of that series. We are not, however, much advanced in our inquiry in consequence of this remark; for the first terms of all the series, which can, on any hypothesis, express

VOL. II.

z

the

* Euc. Lib. IV. Prop. 15.

† See these tables, *Ast. Ind.* p. 414.

the relation of the equation of the centre to the anomaly of a planet, are so far the same, that they are proportional to the sine of that anomaly; and it becomes therefore necessary to search among these hypotheses, for that by which the series of small differences, described above, may be best represented. It is needless to enter here into any detail of the reasonings by which this has been done, and by which I have found, that the argument in the table bears very nearly the same relation to the corresponding numbers, that the anomaly of the eccentric does to the equation of the centre. By the anomaly of the eccentric, however, I do not mean the angle which is known by that name in the solution of KEPLER'S problem, but that which serves the same purpose with it, on the supposition of a circular orbit, and an uniform angular motion about a point which is not the centre of that orbit, but which is as distant from it, on the one side, as the earth (or the place of the observer) is on the other. It is the angle, which, in such an orbit, the line drawn from the planet to the centre, makes with the line drawn from thence to the apogee; and the argument in the Indian tables coincides with this angle.

THIS hypothesis of a double eccentricity, is certainly not the simplest that may be formed with respect to the motion of the heavenly bodies, and is not what one would expect to meet with here; but it agrees so well with the tables, and gives the equations from the arguments so nearly, especially for the moon and the planets, that little doubt remains of its being the real hypothesis on which these tables were constructed*.

54. OF

* THE formula deduced from this hypothesis, for calculating the equation of the centre from the anomaly of the eccentric, is the following: Let α be the equation of the centre, ϕ the anomaly of the eccentric, e the eccentricity of the orbit, or the tangent of

half the greatest equation; then $\alpha = 2e \sin. \phi + \frac{2e^3 \sin. 3\phi}{3} + \frac{2e^5 \sin. 5\phi}{5} + \&c.$

54. OF this, the method employed to calculate the place of any of the five planets from these tables, affords a confirmation. But, in reasoning about that method, it is necessary to put out of the question the use that is made of the parallax of the annual orbit, or of the *schigram*, in order to have the argument for finding the equation of the centre, which is evidently faulty, as it makes that equation to be affected by a quantity, (the parallax of the annual orbit), on which it has in reality no dependence. To have the rule free from error, it is to be taken, therefore, in the case when there is no parallax of the annual orbit, that is, when the planets are in opposition or conjunction with the sun. In that case, the mean anomaly is first corrected by the subtraction or addition of half the equation that belongs to it in the table. It then becomes the true argument for finding, from that same table, the equation of the centre, which is next applied to the mean anomaly, to have the true. Now, this agrees perfectly with the conclusion above; for the mean anomaly, by the subtraction or addition of half the equation belonging to it in the table, is converted, almost precisely, into the anomaly of the eccentric, and becomes therefore the proper argument for finding out the equation, which is to change the mean anomaly into the true*. There can be no doubt, of consequence, that the conclusion we have come to is strictly applicable to the planets, and that the orbit of each of them, in this astronomy, is supposed to be a circle, the earth not being in its centre, but the angular

≈ 2

velocity

* THIS method of calculation is so nearly exact, that even in the orbit of Mars, the equation calculated from the mean anomaly, rigorously on the principle of his angular motion being uniform, about a point distant from the centre, as described above, will rarely differ a minute from that which is taken out from the Indian tables by this rule. It was remarked, (§ 37.) that it is not easy to explain the rules for finding the argument of the equation of the centre, for the planets. What is said here explains fully one part of that rule, *viz.* the correction made by half the equation *manda*; the principle on which the other part proceeds, *viz.* the correction by half the equation *schigram*, is still uncertain.

velocity of the planet being uniform about a certain point, as far from that centre on the one side, as the earth is on the opposite.

55. BETWEEN the structure of the tables of the equations of the sun and moon, and the rules for using them, there is not the same consistency; for in both of them, the argument, which we have found to be the eccentric anomaly, is nevertheless treated as the mean. So far as concerns the sun, this leads to nothing irreconcilable with our supposition, because the sun's equation being small, the difference will be inconsiderable, whether the argument of that equation be treated as the eccentric or the mean anomaly.

BUT it is otherwise with respect to the moon, where the difference between considering the argument of the equation as the mean, or as the eccentric anomaly, is not insensible. The authority of the precepts, and of the tables, are here opposed to one another; and we can decide in favour of the latter, only because it leads to a more accurate determination of the moon's place than the former. It would indeed be an improvement on their method of calculation, which the Brahmins might make consistently with the principles of their own astronomy, to extend to the moon their rule for finding the equation of the centre for the planets. They would then avoid the palpable error of making the maximum of the moon's equation at the time when her mean anomaly is 90° , and would ascertain her place every where with greater exactness. It is probable that this is the method which they were originally directed to follow.

56. FROM the hypothesis which is thus found to be the basis of the Indian astronomy, one of the first conclusions which presents itself, is the existence of a remarkable affinity between the system of the Brahmins and that of *PTOLEMY*. In the latter, the same thing was supposed for the five planets,
that

that appears in the former to have been universally established, *viz.* that their orbits were circles, having the earth within them, but removed at a small distance from the centre, and that each planet described the circumference of its orbit, not with an uniform velocity, but with one that would appear uniform, if it were viewed from a point as far above the centre of the orbit, as that centre is above the earth. This point was, in the language of PTOLEMY's astronomy, the centre of the *Equant*.

Now, concerning this coincidence, it is the more difficult to judge, as, on the one hand, it cannot be ascribed to accident, and, on the other, it may be doubted, whether it arises necessarily out of the nature of the subject, or is a consequence of some unknown communication between the astronomers of India and of Greece.

THE first hypothesis by which men endeavoured to explain the phenomena of the celestial motions, was that of a uniform motion in a circle, which had the earth for its centre. This hypothesis was, however, of no longer continuance than till instruments of tolerable exactness were directed to the heavens. It was then immediately discovered, that the earth was not the centre of this uniform motion; and the earth was therefore supposed to be placed at a certain distance from the centre of the orbit, while the planet revolved in the circumference of it with the same velocity as before. Both these steps may be accounted necessary; and in however many places of the earth, and however cut off from mutual intercourse, astronomy had begun to be cultivated, I have no doubt that these two suppositions would have succeeded one another, just as they did among the Greek astronomers.

BUT when more accurate observations had shewn the insufficiency even of this second hypothesis, what ought naturally to be the third, may be thought not quite so obvious; and if the Greeks made choice of that which has been described above, it
may

may seem to have been owing to certain metaphysical notions concerning the simplicity and perfection of a circular and uniform motion, which inclined them to recede from that supposition, no farther than appearances rendered absolutely necessary. The same coincidence between the ideas of metaphysics and astronomy, cannot be supposed to have taken place in other countries; and therefore, where we find this third hypothesis to have prevailed, we may conclude that it was borrowed from the Greeks.

57. THOUGH it cannot be denied, that, in this reasoning, there is some weight, yet it must be observed, that the introduction of the third hypothesis did not rest among the Greeks altogether on the coincidence above mentioned. It was one suited to their progress in mathematical knowledge, and offered almost the only system, after the two former were exploded, which rendered the planetary motions the subject of geometrical reasoning, to men little versed in the methods of approximation. This was the circumstance then, which, more than any other, probably influenced them in the choice of this hypothesis, though we are not to look for it as an argument stated in their works, but may judge of the influence it had, from the frequency with which, many ages afterwards, the *αγωναεργησια* of KEPLER's system was objected to him by his adversaries; an objection to which that great man seemed to pay more attention than it deserved.

THERE is reason therefore to think, that in every country where astronomy and geometry had neither of them advanced beyond a certain point, the hypothesis of the equant would succeed to that of a simple eccentric orbit, and therefore cannot be admitted as a proof, that the different systems in which it makes a part, are necessarily derived from the same source. Some other circumstances attending this hypothesis, as it is found in the Indian tables, go still farther, and seem quite inconsistent with the supposition that the authors of these tables
derived

derived it from the astronomers of the west. For, *first*, It is applied by them to all the heavenly bodies, that is, to the sun and moon, as well as the planets. With PROLEMY, and with all those who founded their systems on his, it extended only to the latter, inasmuch that KEPLER's great reformation in astronomy, the discovery of the elliptic orbits, began from his proving, that the hypothesis of the equant was as necessary to be introduced for the sake of the sun's orbit, as for those of the planets, and that the eccentricity in both cases, must be bisected. It is, therefore, on a principle no way different from this of KEPLER, that the tables of the sun's motion are computed in the Indian astronomy, though it must be allowed, that the method of using them is not perfectly consistent with this idea of their construction.

2dly, THE use made of the anomaly of the eccentric in these tables, as the argument of the equation of the centre, is altogether peculiar to the Indian astronomy. PROLEMY's tables of that equation for the planets, though they proceed on the same hypothesis, are arranged in a manner entirely different, and have for their argument the mean anomaly. The angle which we call the anomaly of the eccentric, and which is of so much use in the Indian tables, is not employed at all in the construction of his *, nor, I believe, in those of any other astronomer till the time of KEPLER; and even by KEPLER it was not made the argument of the equation to the centre. The method, explained above, of converting the mean anomaly into that of the eccentric, and consequently into the argument of the equation, is another peculiarity, and though simple and ingenious, has not the accuracy suited to the genius of the Greek astronomy, which never admitted even of the best approximation, when a rigorous solution could be found; and, on the whole, if the resemblance of these two systems, even with all the exceptions that have been stated, must still be ascribed

to

* Almagest. lib. XI. cap. 9. & 10.

to some communication between the authors of them, that communication is more likely to have gone from India to Greece, than in the opposite direction. It may perhaps be thought to favour this last opinion, that PTOLEMY has no where demonstrated the necessity of assigning a double eccentricity to the orbits of the planets, and has left room to suspect, that authority, more than argument, has influenced this part of his system.

58. IN the tables of the planets, we remarked another equation, (*schigram*) answering to the parallax of the earth's orbit, or the difference between the heliocentric and the geocentric place of the planet. This parallax, if we conceive a triangle to be formed by lines drawn from the sun to the earth and to the planet, and also from the planet to the earth, is the angle of that triangle, subtended by the line drawn from the sun to the earth. And so, accordingly, it is computed in these tables; for if we resolve such a triangle as is here described, we will find the angle, subtended by the earth's distance from the sun, coincide very nearly with the *schigram*.

THE argument of this equation is the difference between the mean longitude of the sun and of the planet. The orbits are supposed circular; but whether the inequality in question was understood to arise from the motion of the earth, or from the motion of the planet in an epicycle, the centre of which revolves in a circle, is left undetermined, as both hypotheses may be so adjusted as to give the same result with respect to this inequality. The proportional distances of the planets from the earth or the sun, may be deduced from the tables of these equations, and are not far from the truth.

59. THE preceding calculations must have required the assistance of many subsidiary tables, of which no trace has yet been found in India. Besides many other geometrical propositions, some of them also involve the ratio, which the diameter of a circle was supposed to bear to its circumference, but which

we would find it impossible to discover from them exactly, on account of the small quantities that may have been neglected in their calculations. Fortunately, we can arrive at this knowledge, which is very material when the progress of geometry is to be estimated, from a passage in the *Ayeen Akbery*, where we are told, that the Hindoos suppose the diameter of a circle to be to its circumference as 1250 to 3927*, and where the author, who knew that this was more accurate than the proportion of ARCHIMEDES, (7 to 22), and believed it to be perfectly exact, expresses his astonishment, that among so simple a people, there should be found a truth, which, among the wisest and most learned nations, had been sought for in vain.

THE proportion of 1250 to 3927 is indeed a near approach to the quadrature of the circle; it differs little from that of METIUS, 113 to 355, and is the same with one equally remarkable, that of 1 to 3.1416. When found in the simplest and most elementary way, it requires a polygon of 768 sides to be inscribed in a circle; an operation which cannot be arithmetically performed without the knowledge of some very curious properties of that curve, and, at least, nine extractions of the square root, each as far as ten places of decimals. All this must have been accomplished in India; for it is to be observed, that the above mentioned proportion cannot have been received from the mathematicians of the west. The Greeks left nothing on this subject more accurate than the theorem of ARCHIMEDES; and the Arabian mathematicians, seem not to have attempted any nearer approximation. The geometry of modern Europe, can much less be regarded as the source of this knowledge. METIUS and VIETA were the first, who, in the quadrature of the circle, surpassed the accuracy of ARCHIMEDES; and they flourished at the very time when the Institutes of AKBAR were collected in India.

60. ON the grounds which have now been explained, the following general conclusions appear to be established.

I. THE observations on which the astronomy of India is founded, were made more than three thousand years before the Christian era ; and, in particular, the places of the sun and moon, at the beginning of the Calyougham, were determined by actual observation.

THIS follows from the exact agreement of the radical places in the tables of Tirvalore, with those deduced for the same epoch from the tables of DE LA CAILLE and MAYER, and especially in the case of the moon, when regard is had to her acceleration. It follows, too, from the position of the fixed stars in respect of the equinox, as represented in the Indian zodiac ; from the length of the solar year ; and, lastly, from the position and form of the orbits of Jupiter and Saturn, as well as their mean motions ; in all of which, the tables of the Brahmins, compared with ours, give the quantity of the change that has taken place, just equal to that which the action of the planets on one another may be shown to have produced, in the space of forty-eight centuries, reckoned back from the beginning of the present.

Two other of the elements of this astronomy, the equation of the sun's centre, and the obliquity of the ecliptic, when compared with those of the present time, seem to point to a period still more remote, and to fix the origin of this astronomy 1000 or 1200 years earlier, that is, 4300 years before the Christian era ; and the time necessary to have brought the arts of calculating and observing to such perfection as they must have attained at the beginning of the Calyougham, comes in support of the same conclusion.

OF such high antiquity, therefore, must we suppose the origin of this astronomy, unless we can believe, that all the coincidences

cidences which have been enumerated, are but the effects of chance ; or, what indeed were still more wonderful, that, some ages ago, there had arisen a NEWTON among the Brahmins, to discover that universal principle which connects, not only the most distant regions of space, but the most remote periods of duration ; and a DE LA GRANGE, to trace, through the immensity of both, its most subtle and complicated operations.

II. THOUGH the astronomy which is now in the hands of the Brahmins, is so ancient in its origin, yet it contains many rules and tables that are of later construction.

THE first operation for computing the moon's place from the tables of Tirvalore, requires that 1,600,984 days should be subtracted from the time that has elapsed since the beginning of the Calyougham, which brings down the date of the rule to the year 1282 of our era. At this time, too, the place of the moon, and of her apogee, are determined with so much exactness, that it must have been done by observation, either at the instant referred to, or a few days before or after it. At this time, therefore, it is certain, that astronomical observations were made in India, and that the Brahmins were not, as they are now, without any knowledge of the principles on which their rules are founded. When that knowledge was lost, will not perhaps be easily ascertained ; but there are, I think, no circumstances in the tables from which we can certainly infer the existence of it at a later period than what has just been mentioned ; for though there are more modern epochs to be found in them, they are such as may have been derived from the most ancient of all, by help of the mean motions in the tables of Chrisnabouram *, without any other skill than is required to an ordinary calculation. Of these epochs, beside what have been occasionally mentioned in the course of our remarks, there is one (involved in the tables of Narfapur) as late as the year 1656, and another as early as the year 78 of our era,

a a 2

which

* Aft. Ind. p. 307.

which marks the death of SALIVAGANAM, one of their princes, in whose reign a reform is said to have taken place in the methods of their astronomy. There is no reference to any intermediate date, from that time to the beginning of the Calyougham.

THE parts of this astronomy, therefore, are not all of the same antiquity; nor can we judge, merely from the epoch to which the tables refer, of the age, to which they were originally adapted. We have seen, that the tables of Chirsnabouram, though they profess to be no older than the year 1491 of our era, are, in reality, more ancient than the tables of Tirvalore, which are dated from the Calyougham, or at least have undergone fewer alterations. This we concluded from the slow motion given to the moon, in the former of these tables, which agreed, with such wonderful precision, with the secular equation applied to that planet by MAYER, and explained by M. DE LA PLACE.

BUT it appears, that neither the tables of Tirvalore or Chirsnabouram, nor any with which we are yet acquainted, are the most ancient to be found in India. The Brahmins constantly refer to an astronomy at Benares, which they emphatically style *the ancient* *, and which they say is not now understood by them, though they believe it to be much more accurate than that by which they calculate. That it is more accurate, is improbable; that it may be more ancient, no one who has duly attended to the foregoing facts and reasonings, will think impossible; and every one, I believe, will acknowledge, that no greater service could be rendered to the learned world, than to rescue this precious fragment from obscurity. If that is ever to be expected, it is when the zeal for knowledge has formed a literary society among our countrymen in Bengal, and while that society is directed by the learning and abilities of Sir WILLIAM JONES. Indeed, the farther discoveries

* Ast. Ind. p. 309. M. LE GENTIL, Mem. Acad. Scien. 1772. P. II. p. 221.

ries which may be made with respect to this science, do not interest merely the astronomer and the mathematician, but every one who delights to mark the progress of mankind, or is curious to look back on the ancient inhabitants of the globe. It is through the medium of astronomy alone that a few rays from those distant objects can be conveyed in safety to the eye of a modern observer, so as to afford him a light, which, though it be scanty, is pure and unbroken, and free from the false colourings of vanity and superstition.

III. THE basis of the four systems of astronomical tables which we have examined, is evidently the same.

THOUGH these tables are scattered over an extensive country, they seem to have been all originally adapted, either to the same meridian, or to meridians at no great distance, which traverse what we may call the classical ground of India, marked by the ruins of Canoge, Palibothra and Benares. They contain rules that have originated between the tropics; whatever be their epoch, they are all, by their mean motions, connected with that of the Calyougham; and they have besides one uniform character which it is perhaps not easy to describe. Great ingenuity has been exerted to simplify their rules; yet, in no instance almost, are they reduced to the utmost simplicity; and when it happens that the operations to which they lead are extremely obvious, these are often involved in an artificial obscurity. A Brahmin frequently multiplies by a greater number than is necessary, where he seems to gain nothing but the trouble of dividing by one that is greater in the same proportion; and he calculates the era of SALIVAGANAM with the formality of as many distinct operations as if he were going to determine the moon's motion since the beginning of the Calyougham. The same spirit of exclusion, the same fear of communicating his knowledge, seems to direct the calculus which pervades the religion of the Brahmin; and, in neither of them, is he willing to receive or to impart instruction. With all these circumstances of resemblance,

blance, the methods of this astronomy are as much diversified as we can suppose the same system to be, by passing through the hands of a succession of ingenious men, fertile in resources, and acquainted with the variety and extent of the science which they cultivated. A system of knowledge, which is thus assimilated to the genius of the people, that is diffused so widely among them, and diversified so much, has a right to be regarded, either as a native, or a very ancient inhabitant of the country where it is found.

IV. THE construction of these tables implies a great knowledge of geometry, arithmetic, and even of the theoretical part of astronomy.

IN proof of this, it is unnecessary to recapitulate the remarks that have been already made. It may be proper, however, to add, that the method of calculating eclipses, to which these tables are subservient, is, in no respect, an empirical one, founded on the mere observation of the intervals at which eclipses return, one after another, in the same order. It is indeed remarkable, that we find no trace here of the period of 6585 days and 8 hours, or 223 lunations, the *Saros* of the Chaldean astronomers, which they employed for the prediction of eclipses, and which (observed with more or less accuracy) the first astronomers every where must have employed, before they were able to analyse eclipses, and to find out the laws of every cause contributing to them. That empirical method, if it once existed in India, is now forgotten, and has long since given place to the more scientific and accurate one, which offers a complete analysis of the phenomena, and calculates, one by one, the motions of the sun, of the moon, and of the node.

BUT what, without doubt, is to be accounted the greatest refinement in this system, is the hypothesis employed in calculating the equations of the centre for the sun, moon and planets, that, *viz.* of a circular orbit having a double eccentricity,
or

or having its centre in the middle, between the earth and the point about which the angular motion is uniform*. If to this we add the great extent of geometrical knowledge requisite to combine

* It should have been remarked before, that M. BAILLY has taken notice of the analogy between the Indian method of calculating the places of the planets, and PROLEMY's hypothesis of the equant, though on different principles from those that have been followed here, and such as do not lead to the same conclusion. In treating of the question, whether the sun or earth has been supposed the centre of the planetary motions by the authors of this astronomy, he says, “ Ils semblent avoir reconnu que les deux inégalités (l'équation du centre et la parallaxe de l'orbe annuel) étoient vues de deux centres differens ; et dans l'impossibilité où ils étoient de déterminer et le lieu et la distance des deux centres, ils ont imaginé de rapporter les deux inégalités à un point qui tint le milieu, c'est-à-dire, à un point également éloigné du soleil, et de la terre. Ce nouveau centre ressemble assez au centre de l'équant de PROLEMEE. (Astr. Ind. Disc. Prel. p. 69.) The fictitious centre, which M. BAILLY compares with the equant of PROLEMY, is therefore a point which bisects the distance between the sun and earth, and which, in some respects, is quite different from that equant ; the fictitious centre, which, in the preceding remarks, is compared with the equant of PROLEMY, is a point of which the distance from the earth is bisected by the centre of the orbit, precisely as in the case of that equant. M. BAILLY draws his conclusion from the use made of half the equation *schigram*, as well as half the equation *manda*, in order to find the argument of this last equation. The conclusion here is established, by abstracting altogether from the former, and considering the cases of oppositions and conjunctions, when the latter equation only takes place. If, however, the hypothesis of the equant shall be found of importance in the explanation of the Indian astronomy, it must be allowed that it was first suggested by M. BAILLY, though in a sense very different from what it is understood in here, and from what it was understood in by PROLEMY.

For what farther relates to the parts of the astronomy of Chaldea and of Greece, which may be supposed borrowed from that of India, I must refer to the 10th Chap. of the *Astronomie Indienne*, where that subject is treated with great learning and ingenuity. After all, the silence of the ancients with respect to the Indian astronomy, is not easily accounted for. The first mention that is made of it, is by the Arabian writers ; and M. BAILLY quotes a very singular passage, where MASSOUDI, an author of the 12th century, says, that BRAMA composed a book, entitled, *Sind-Hind*, that is, *Of the Age of Ages*, from which was composed the book *Maghifi*, and from thence the *Almagest* of PROLEMY. Astr. Ind. Disc. prel. p. 175.

THE fabulous air of this passage is, in some measure, removed, by comparing it with one from ABULFARAGIUS, who says, that, under the celebrated AL MAIMON, the 7th Khalif of Babylon, (about the year 813 of our era) the astronomer HABASH composed three sets of astronomical tables, one of which was *ad regulas Sind Hind* ; that is, as Mr COSTARD explains it, according to the rules of some Indian treatise of astronomy. (Asiatic Miscel. Vol. I. p. 34.) The *Sind-Hind* is therefore the name of an astronomical book that existed in India in the time of HABASH, and the same, no doubt, which MASSOUDI says was ascribed to BRAMA.

combine this, and the other principles of their astronomy together, and to deduce from them the just conclusions; the possession of a calculus equivalent to trigonometry; and, lastly, their approximation to the quadrature of the circle, we shall be astonished at the magnitude of that body of science, which must have enlightened the inhabitants of India in some remote age, and which, whatever it may have communicated to the western nations, appears to have received nothing from them.

SUCH are the conclusions that seem to me to follow, with the highest probability, from the facts which have been stated. They are, without doubt, extraordinary; and have no other claim to our belief, except that, as I think has been fully proved, their being false were much more wonderful than their being true. There are but few things, however, of which the contrary is impossible. It must be remembered, that the whole evidence on this subject is not yet before the public, and that the repositories of Benares may contain what is to confirm or to invalidate these observations.