

LV. *A Discourse on the Parallax of the Sun. By the Rev. Thomas Hornsby, M. A. Savilian Professor of Astronomy in the University of Oxford, and F. R. S.*

Read Dec. 23, 1763. **T**HE quantity of the Sun's parallax is of such importance both to the theory and practical part of astronomy, that every method of determining it hath been employed by the astronomers of every age. Mr. Flamsteed informs us, in the 92d and 96th numbers of the Philosophical Transactions, that from some observations made upon the planet Mars, he had found the Sun's parallax not to exceed 10 seconds; and Dr. Halley, in a memoir written expressly with a view to ascertain the exact quantity of it, supposes it not to be greater than  $12'' \frac{1}{2}$ .

When we consider the imperfect state of astronomy at the time when Mr. Horrox lived, we cannot sufficiently admire the wonderful genius of that young gentleman, who at the age of 24 could collect from his own observations, that the parallax of the Sun did not exceed 14 seconds; while many celebrated astronomers, whose tables were then in the greatest repute, had assigned a parallax of more than two minutes to the Sun, which Kepler had supposed could not be less than 59 seconds, and which Hevelius, who published the admirable treatise of Mr. Horrox, intitled, *Venus in Sole visa*, fixed at 41 seconds.

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In the year 1719, Dr. Pound and his nephew, that illustrious astronomer, Mr. Bradley, did, when Mars was in opposition to the Sun, demonstrate (to use the words of Dr. Halley, *Phil. Transf.* N<sup>o</sup>. 366, p. 114.) the extreme minuteness of the Sun's parallax, and that it was not more than 12'', nor less than 9'', upon many repeated trials. At the same time and by the same kind of observations Mr. Maraldi determined this parallax to be 10', the result of his observations agreeing exactly with those deduced from the correspondent observations by Mr. Richer at Cayenne and by Mr. Cassini at Paris in the year 1672.

The voyage which the Abbè de la Caille undertook, to perfect a catalogue of some of the principal fixed stars, furnished the astronomers with the means of determining the Sun's parallax by corresponding altitudes of the planets Mars and Venus, to be observed on each side of the equator, with all the accuracy of which that method is capable. The astronomers here in Europe were invited to determine the distances of the planets from particular stars on stated days, while the Abbè himself proposed to make the corresponding observations on the southernmost part of Africa at the Cape of Good Hope. By the differences of the altitudes of the northern limb of Mars and of such stars as were nearly in the same parallel observed on the same day at the Cape with a sextant of 6 f. radius; at Greenwich by Dr. Bradley with a mural quadrant of 8 f.; at Bologna in Italy by M. Zanotti with a similar instrument of 5 f.; at the Royal Observatory at Paris by Messieurs Cassini de Thury and Gentil with a moveable quadrant of 6 f.; and in Sweden by Messieurs Wargentin, Stronmer and Schem-

Schemmark, with telescopes of 7 and 8 f. armed with micrometers, it was found, when every reduction is made, that, according to each observation, the dates of which are given below, the horizontal parallax of the Sun, when at its mean distance from the earth, was as is represented in the following table.

Greenwich.		Bologna.		Paris.		Stockholm.		Upfal.		Hernofand.	
1751.	"	1751.	"	1751.	"	1751.	"	1751.	"	1751.	"
Aug. -- 30	9, 677	Aug. 31	9, 753	Sept. 13	9, 134	Sept. 1	10, 466	Sept. 2	9, 438	Sept. 25	9, 933
Sept. -- 13	9, 324	Sept. 1	9, 895	14	9, 715	25	10, 504	+ 24	12, 255	27	10, 618
14	9, 096	13	9, 971	+ 24	11, 912	Oct. + 3	12, 864	25	9, 715		
Oct. -- 3	10, 161	14	10, 238	Oct. 8	9, 895	5	10, 085	Oct. 6	9, 134		
4	10, 504	Oct. + 7	11, 075			6	9, 735				
7	9, 515										
+ 9	10, 961										
Mean of all	9, 891		10, 186		10, 164		10, 734		10, 135		10, 275
Mean rej. †	9, 712		9, 964		9, 581		10, 202		9, 421		

By taking a mean of all the observations, it follows that the Sun's mean horizontal parallax is 10'', 2; and if we reject the observations which differ most in excess from the rest, the mean will give 9,842 for the Sun's mean horizontal parallax.

Besides these 27 determinations, the Abbè de la Caille compared 41 observations, the mean of which is given in the following table.

N <sup>o</sup> of Obs.	Observations.	Instruments.	Places.	☉ Par.
7	The late M. Caffini and M. Maraldi	Quadrant 2 f. rad.	Thury	8, 982
6	Mr. Delisle — at the Hotel de Clugny	Mur. circle 2 f.	Paris †	11, 532
3	Father Beraud	Refr. tel. 7 f.	Lyons	9, 020
6	M. M. Garipuy and d'Arquier	Ditto.	Toulouse	8, 944
12	M. Sabatelli and Father Carcani	Quad. 4f. diag. div.	Naples	9, 933
7	M. Bofe	Tel. of 6 and 8 f.	Wittemberg	10, 999
	Mean of all observ. according to A. Caille			10, 210
	Mean of Results (rejecting the 2d)			9, 575

Few observations of Venus near the inferior conjunction with the Sun on Oct. 31. 1751 were made, on account of the unfavourable weather here in Europe. By an observation made at Greenwich on Oct. 25, the mean horizontal parallax was  $9'',8$ ; but according to the observation made at Paris on the same day at the Royal Observatory, that parallax was  $11'',4$ . On Oct. 27, by an observation made at Paris, the  $\odot$ 's mean horizontal parallax was  $9'',85$ ; but by an observation at Bologna on the same day it was found to be  $10'',4$  — By the observation at Paris on Nov. 17, the Sun's mean parallax was  $10'',5$ . By a mean of all the observations of Venus, the Sun's mean parallax is  $10'',38$ ; and if we reject the Paris observation on Oct. 25, that parallax is  $10'',13^*$ .

We see then that, according to these observations, the Sun's mean horizontal parallax is not less than  $8'',94$ . If we take a mean of the whole, that quantity is  $10,09$ : But if we reject the observations that differ most in excess, the Sun's mean horizontal parallax will be found to be  $9'',92$  a determination in which every astronomer might readily acquiesce, when he considers the accuracy of the observers and the nice agreement of almost all the observations.

And such was the state of the Sun's parallax as deduced from the latest and best observations, when the approaching transit of Venus in 1761 engaged the attention of the curious of all nations. Dr. Halley, in *Philosophical Transactions*, N<sup>o</sup>. 348, had proposed a method of determining the Sun's parallax

\* See the Abbè de la Caille's Introduction to his *Ephemerides Cælestes* from 1765 to 1774.

by procuring observations to be made upon this transit in such places where the difference of time between the ingress and egress would be the greatest possible; namely near the mouth of the Ganges, where the Sun would be vertical at the middle of the transit, and at Port-Nelson in Hudson's-Bay, where the planet would enter upon the Sun's disk about the time of sunset, and leave it soon after sun-rising; for in the former place, says Dr. Halley, the planet would be equally distant from noon both at ingress and egress, and the apparent motion of Venus upon the Sun would be accelerated by almost double the quantity of the horizontal parallax of Venus from the Sun: because Venus is at that time retrograde, and moves in a direction contrary to that of the eye of an observer upon the earth's surface. Whereas in Hudson's-Bay, under an opposite meridian, the eye of an observer will be carried, while the Sun seems to move under the pole from setting to rising, in a direction contrary to the motion of the observer's eye at the Ganges; that is, in the direction of the planet's retrograde motion from east to west.—From these considerations, and supposing with Dr. Halley the axis of the planet's path to be inclined to the axis of the equator in an angle of  $2^{\circ}.18'$  only, the interval between the two contacts would have been  $15'.10''$  longer in Hudson's Bay than at the mouth of the Ganges.

But upon examination the case is found to be somewhat different. The axis of the equator on the 6th of June 1761 made an angle of  $6^{\circ}.10'$  with the axis of the ecliptic on one side, and the axis of the planet's path an angle of  $8^{\circ}.30'.10''$  on the other; the axis of the planet's path therefore made an angle with the equator of  $14^{\circ}.40'.10''$ .—The planet's latitude was  $5\frac{1}{4}$  minutes greater both from observation and

the Doctor's own tables, than he had supposed in his calculation made from the Rodolphine tables corrected: and therefore the planet's egress could not have been observed at Port Nelson. Having made a computation for a place in North America situated  $5^{\text{h}}. 30'$  to the west of Greenwich, and in the 60th degree of latitude; and also for a place to the east of Ganges, and  $6^{\text{h}}. 30'$  to the east of Greenwich in the latitude of  $22^{\circ}. 42'$  north, that the places might be nearly situated in the same circumstances with the mouth of the Ganges and Port Nelson, I find that the interval between the two contacts would be but  $4'. 56''$  longer in America than in the East Indies, supposing the Sun's parallax  $12''.5$ , and the inclination of Venus's path  $14^{\circ}. 40'$  to the equator.

And here perhaps it may not be altogether unnecessary to enquire how far the mistake which Dr. Halley committed, by using the difference of the two angles instead of their sum, would influence the times of the transit as seen at Ganges and Port Nelson. For this purpose I made use of the same elements which Dr. Halley has given in his paper, and calculated the angle of the vertical with the orbit of Venus at the two internal contacts at both places, supposing the orbit to be inclined first only  $2^{\circ}. 18'$  to the equator, agreeably to Dr. Halley's supposition, and also  $14^{\circ}. 40'$ . and I found that the duration would be  $15'. 13''$  longer at Hudson's-Bay than at the Ganges upon the first supposition; and  $14'. 44''$ , if the circles be duly inclined to each other; the difference being only 29 seconds. It has already been found by calculation, supposing the latitude of Venus to be about  $9 \frac{1}{2}$  minutes, that the difference of duration at the two places would have been only  $4'. 56''$ . It may fairly

fairly therefore be concluded that the transposition of the circles contributed very little towards giving so different a result, the reason of which need not here be mentioned; and Dr. Halley seems to have been led into the mistake entirely from supposing the latitude of Venus to be about  $4'.0''$  according to the tables, which he then used, constructed upon the principle that the nodes of that planet were fixed.— Having determined that the difference of duration at the two places above mentioned would be  $15'.10''$  (differing only  $3''$  from the method I used which is independent of projection) the Doctor proceeds to shew, that if Venus had no latitude at the time of the middle of the transit, the difference would be  $18'.40''$ ; and if the planet should pass  $4'.0''$  to the north of the Sun's center, that difference would be  $21'.40''$ , and would become still greater, if the planet's north latitude should be farther increased. And such would have been the event, had the motion of the nodes been progressive. But, agreeably to the principles of universal attraction, their motion is really retrograde, and this Dr. Halley says he himself suspected, *ut ob nuperas quasdam observationes suspicio est*. And therefore it is somewhat surprising that he did not determine by calculation what would have been the difference in the whole duration between the two places, if Venus should pass more to the southward of the Sun's center, then he had supposed. He would then immediately have perceived that the two stations were not so advantageously placed, as the solution of the problem required.

Observers were therefore to be sent to other places, in order to determine the Sun's parallax agreeably to the method proposed by Dr. Halley. The city of  
Tobolski

Tobolski in Siberia is so situated, that the interval between the two contacts was perhaps as short as could possibly be observed on any part of the earth's surface; to this place was sent the Abbè Chappé d'Au-teroches, one of the French astronomers. Near Hud-son's Bay and in  $60^\circ$  of latitude the duration would have been 5 minutes longer, supposing the Sun's parallax =  $9''$ . At Bencoolen, where it was first proposed to send Mefs. Mason and Dixon, the difference would have been about  $4\frac{1}{2}$  minutes. At the island of Rodrigues, where Mr. Pingré could only observe the last internal contact, the difference would have been about  $7\frac{1}{2}$  minutes. On the southern coast of New-Holland, it would have been somewhat more than 10 minutes. And in the great Indian Ocean, under  $115\frac{1}{4}$  of absolute longitude from the Isle of Ferro and in  $57^\circ$  of south latitude, where the begin-ning of the transit would happen soon after Sun-ris-ing, and the end just before Sun-set, the difference would amount to  $13\frac{1}{4}$  minutes. The greatest differ-ence between the interval of the two internal contacts, as determined by actual observation on the 6th of June, was  $2'.49'',75$ , a quantity hardly sufficient to determine the Sun's parallax agreeably to the method proposed by Dr. Halley.

I have however made the necessary calculations, and compared the duration of the transit observed at several places with the duration as observed at To-bolski. The parallax resulting from each observation is contained in the following table, in which the 3d column contains the observed duration, the 4th the difference of each observed duration; the next con-tains that difference as deduced by computation upon a supposition that the Sun's parallax is  $9''$ . In the  
last



last column is given the horizontal parallax on the day of the transit, resulting from a comparison of the 4th and 5th columns.

Places.	Observers.	Observed duration.	Difference of observ'd dur.	Difference by calculation.	Sun's Parallax.
		h ' "	" "	" "	" "
Tobolski	Abbe Chappe	5 48 53,25			
Cajaneburg	Mr. Planmann	5 49 54	1 00, 75	1 00, 88	8, 980
Tornea°	Hellant	5 50 09	1 15, 75	1 05, 27	10, 444
Tornea°	Lagerborn	5 50 21	1 27, 75	1 05, 27	+12, 098
Upsal	Bergman	5 50 26	1 32, 75	1 33, 78	8, 901
Upsal	Mallet	5 50 07	1 13, 75	1 33, 78	+ 7, 077
Upsal	Strömer	5 50 02	1 08, 75	1 33, 78	+ 6, 597
Hernofand	Gifter	5 50 26	1 32, 75	1 25, 76	9, 733
Abo	Justander	5 50 09	1 15, 75	1 20, 68	8, 450
Stockholm	Wargentin	5 50 45	1 51, 75	1 34, 21	10, 675
Stockholm	Klingenshiern	5 50 42	1 48, 75	1 34, 21	10, 389
Calcutta	Magee	5 50 31	1 37, 75	1 37, 02	9, 067
Madras	Hirft	5 51 43	2 49, 75	2 39, 50	9, 577
Mean of the whole - - - - -					9, 332
Mean, rejecting 2 observations at Upsal and 1 at Tornea-					9, 579

The duration at Cajaneburg was the shortest except at Tobolski; with which if we compare the duration observed at Madras the parallax is 9'',948; and by taking a mean of the parallax deduced from a comparison of the observation at Madras with those of Tobolski and Cajaneburg, the parallax is 9'',762.

The observations at the above places agree as well together as can be expected from such small differences in the duration, which must in some measure be influenced by the necessary and unavoidable errors in observation.

If the quantity of the sun's diameter, and the least distance of the centers were very exactly known, the Sun's parallax might safely be determined by comparing the duration of the transit as observed at different places with the duration as supposed to be seen from the earth's center. According to this method, supposing the least distance of the centers to be  $9'.29''\frac{1}{2}$ , which is a mean between the Greenwich Shirburn and Paris observations, and the difference of the semidiameters of the Sun and Venus =  $916''\text{,}4$ , the duration as observed at Tobolski was more than 10 minutes shorter than if seen without parallax; at Tornea°, at Stockholm, at Cajaneburg, at Astracan, and indeed in almost every part of Europe and Asia, the duration was considerably shortened; and if a number of good observations made in several of those parts were procured, the Quantity of the Sun's, parallax might be well enough ascertained, as the difference in duration for a difference of one second in the Sun's parallax will be found very considerable.

Tho' this method should not be practised, unless the necessary requisites for the computation be known with some degree of precision, I have ventured to compare the durations observed chiefly in the northern parts of Europe, and some in Asia, with the duration, as seen from the earth's center, =  $5^{\text{h}}.59'.19''\text{,}10$  mean time, or  $5^{\text{h}}.59'.16''\text{,}64$  apparent time, and calculated from the elements above mentioned.

Places.	Observed durations.	Duration without parallax.	Difference of durations.	Differ. for 1'' of parallax.	Sun's parallax.
	h	h	'	'	'
Tobolski -	5 48 53 25	5 59 16, 64	10 23, 39	64, 09	9, 726
Cajaneburg -	5 49 54		9 22, 64	57, 32	9, 815
Tornea° -	5 50 09		9 17, 64	56, 83	9, 636
Tornea° -	5 50 21		8 55, 64	56, 83	9, 425
Abo - -	5 50 09		9 07, 64	55, 12	9, 935
Upfal - -	5 50 26		8 50, 64	53, 67	9, 888
Upfal - -	5 50 07		9 09, 64	53, 67	10, 241
Upfal - -	5 50 02		9 15, 64	53, 67	10, 352
Hernofand	5 50 26		8 50, 64	53, 65	9, 890
Stockholm	5 50 42		8 34, 64	53, 62	9, 579
Stockholm	5 50 45		8 31, 64	53, 62	9, 523
Calcutta -	5 50 36		8 40, 64	53, 31	9, 766
Madras -	5 51 43		7 33, 64	46, 36	9, 785

N. B. The 4th column contains the difference between the observed and calculated duration; in the 5th is given the difference in the duration for a difference of 1'' in the  $\odot$ 's parallax, and the 6th column is obtained by dividing the 4th by the 5th.

The mean of all the results is 9'',812: and if we reject two of the observations at Upfal, which differ most in excess, the Sun's parallax is 9'',724, agreeing very nearly with the quantity resulting from a comparison of some of the observed durations with the shortest observed at Tobolski and Cajaneburg.

We may also proceed to find the Sun's parallax by means of the least distance of the centers as observed in two or more places where the effect of parallax was contrary; or if the least distance of the centers was only determined at one place, it may be found by calculation at any other place, where the total duration was observed. But in this and the last case the elements of calculation are required with so rigorous

exactness, that perhaps these methods are only to be called in to illustrate and confirm the others.

Mr. Pingré confined himself principally to the determination of the least distance of the centers. At  $21^{\text{h}}.43'.11''$  he found the distance between the nearest limbs of Venus and the Sun to be the greatest  $= 5'.57''.2$ . or  $5'.57''.4$  when corrected by refraction. This distance being subtracted from  $15'.19''.5$  the difference of the Semidiameters, leaves  $9'.22''.1$  for the least apparent distance of the centers. But as that observation was made rather too late, when the distance of the centers was greater than it ought to be, he found by calculation that it should be diminished by  $0''.22$ . The true apparent least distance of the centers by actual observation was therefore  $9'.21''.88$ . In order to be more secure of this result, Mr. Pingré compared a large number of observed distances, both at the beginning and towards the middle of the transit, with the distance determined by internal contact, and after excluding every doubtful observation, he found the least apparent distance of the centers to be  $9'.21''.69$ . By comparing this distance with the distance deduced from the total duration as observed at any place (the method of finding which he has given at large in his memoir inserted in the Memoirs of the academy of sciences for 1761) and by knowing from calculation what influence a parallax of  $10''$  for instance would have upon those distances, he found the Sun's parallax as in the following table.

Places,	Observed durations,		L. distance of centers from the durations,	L. distance deduced from calculation,	Sun's parallax.
	h		' "	' "	"
Tobolski - - - -	5	48 53, 25	9 51, 53	9 52, 24	10, 125
Stockholm - - - -	5	50 43, 5	9 54, 85	9 55, 83	10, 03
Upsal - - - - -	5	50 26	9 55, 62	9 55, 95	10, 23
Cajaneburg - - - -	5	49 54	9 55, 61	9 55, 61	10, 00
Tornea° - - - - -	5	50 09	9 55, 28	9 56, 08	10, 09

By taking a mean of these determinations, we find the Sun's parallax to be  $10'', 1$ . In the above calculations the Sun's semi-diameter was supposed =  $15'.48'', 5$ , and that of Venus  $29''$ . Observers, says Mr. Pingré, have found the former to be about  $2''$  less, and the latter on the contrary half a second larger. By calculating upon the supposition of a difference of  $2''$  in the difference of the semidiameters of the Sun and Venus, the least distance of the centers at Tobolski, Stockholm, Upsal, Tornea°, and Cajaneburg, ought to be  $3'', 12$  less, and at Rodrigues  $2'', 56$  or  $2'', 60$ , and the Sun's horizontal parallax ought also to be  $0'', 17$  less. If then this correction be admitted, which is warranted by the best observations, the Sun's horizontal parallax will be  $9'', 92$ .

There is still another method by which we are enabled to determine the Sun's parallax, by comparing the observations made in different places where the effect of parallax upon the planet is considerable at the times of the two contacts. It was more convenient to make use of the 2d internal contact for this purpose, and the observers were very advantageously stationed at St. Helena and the Cape of Good

Hope: for by comparing the observations made there with those at Tornea°, Tobolski, and in some of the Eastern parts of Asia, the difference of the times of the contacts when reduced to the same meridian will be found to be very considerable, amounting to more than  $9\frac{1}{2}$  minutes at the two first places above mentioned, and being greater, as the places are farther situated to the North-East. But if this method be used, it is absolutely necessary that the longitudes of the places should be determined with the utmost accuracy, since an error of a few seconds would have a considerable influence upon the result, and would increase or diminish the quantity of the Sun's parallax, in proportion. The unfavourable state of the heavens at the time of the internal contact prevented the Rev. Mr. Maskelyne from making an observation at the Isle of St. Helena; which is the more to be lamented as his observation would have confirmed or corrected the observation at the Cape, if necessary; since the effect of parallax at both places would have been very nearly the same. The observers at the Cape were more fortunate, and differed only 4'' in their observation of the internal contact. — But before we proceed to deduce the quantity of the Sun's parallax, by comparing as well the observation made at Greenwich as those at other places, with the observation at the Cape, it will be necessary to lay before the reader the authorities upon which the longitude of each place has been determined.

The longitude of the Cape of Good-Hope was not even nearly known till the Abbé de la Caille went thither in the year 1751. By a comparison of 9 eclipses of Jupiter's satellites as well immersions as emersions observed at the Cape with the correspond-

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ing observations made at Paris, the Cape was found by the Abbé de la Caille himself to be  $1^{\text{h}}.4'.14''$  to the East of Paris, or  $1^{\text{h}}.13'.31''$  to the East of Greenwich. Mess. Mason and Dixon observed many eclipses of Jupiter's satellites at the Cape, but the weather was not so favourable here in England. However by comparing four observations made in Surry-Street and one at Greenwich with those made at the Cape, the difference of longitude at a mean is found to be  $1^{\text{h}}.13'.28'$ , which I have used in the following computations.

The internal contact, as reduced from sidereal to apparent time by Mr. Mason, happened at  $21^{\text{h}}.39'.52''$ . — But upon examination it will be found to have happened later: for whether we make use of the Sun's mean R. ascension from the best solar tables extant, or the Sun's apparent R. ascension reduced to the meridian of the place as determined by actual observation on the day of the transit, the true apparent time of the contact will be found to have happened at  $21^{\text{h}}39'.54$  — or at  $21^{\text{h}}39'.54'' \frac{1}{2}$  if the time by the star Antares be used, whose situation was more favourable to an observer in  $34^{\circ}$ . of South latitude. I shall therefore suppose the internal contact to have happened at  $21^{\text{h}}.39'.52''$  by taking a mean of the two observations\*.

The Royal Observatory at Paris was supposed by Sir Isaac Newton, in his Principia, to be  $9'.20''$  to the East of Greenwich. And the editor of Dr. Hal-

\* Mr. Mason, before he left England, acknowledged, in a letter to me, that he had committed a mistake in his calculation, by forgetting to apply to the Sun's place the equation of præcession, which on the day of the transit amounted to —  $15'',6$ .

ley's tables has followed that determination, which has also been generally used by the English Astronomers. — The French Astronomers have till very lately imagined the difference of meridians to be  $9'.10''$ . as deduced from a single observation of an eclipse of Jupiter's first satellite made by Mr. Cassini when in London, with a telescope of similar size and construction with that used at Paris when the same eclipse was observed. — In the year 1734 Mr. Maraldi published a comparison of 33 eclipses observed at Greenwich by Mr. Flamsteed, and at Paris by the French Astronomers, 19 of which are immersions, and the rest emersions. The longitudes resulting from each correspondent observation differ widely from each other, the two observatories being  $11'.27''$  distant by an immersion of the 2d satellite, and only  $7' 43''$  by an emersion of the first. But if we take a mean of the whole, the difference of longitude will be  $9'.24''$ ; and if we exclude the observation of the 2d satellite above mentioned, which must be very faulty, the difference of meridians will be  $9'.22''$ , a result which in all probability is but a very few seconds from the truth. It may be observed that the immersions all give the difference of longitude too great, and almost all the emersions too little; a circumstance owing either to the badness of the air here in England, or to an inequality in the goodness of the telescopes, or perhaps to both; for whatever was the advantage in observing the immersions, was ballanced by the emersions: for which reason whenever the eclipses of Jupiter's satellites are used, the longitude should, if possible, be deduced both from immersions and emersions.

As the observations of transits of Mercury may be very useful in settling the longitudes of places which  
are



are not far distant, I have examined the several observations that I can meet with made at Paris, and either immediately at Greenwich or in such parts of London whose longitude from Greenwich is known within one second of time. And the result of such comparisons is as follows.

On the 29th of October 1723 Dr. Halley observed the first interior contact of the limbs of Mercury and the Sun at  $2^{\text{h}}.42'.26''$  apparent time at Greenwich. The Rev. Mr. Professor Bradley observed the same at  $2^{\text{h}}.42'.38''$ , at Wansted in Essex ( $10''$  to the East of Greenwich) or at  $2^{\text{h}}.42'.28''$  when reduced to the meridian of Greenwich. Mr. Graham in Fleetstreet observed the same at  $2^{\text{h}}.42'.19''$ , or at  $2^{\text{h}}.42'.44''$ , when reduced to Greenwich. The mean of these is  $2^{\text{h}}.42'.32''.7$ . In the observatory at Paris Mr. Maraldi observed the same at  $2^{\text{h}}.51'.48''$  apparent time; and Mr. Delisle at  $2^{\text{h}}.51'.37'$ , but suspects it might have been some few seconds later. I will suppose it to have happened at  $2^{\text{h}}.51'.43''.5$ . The difference of meridians therefore is  $9'.10''.8$ . If we take a mean of Dr. Halley's and Mr. Bradley's observations only, the difference of meridians is  $9'.16''.5$ .

In the year 1736 Dr. Bevis observed the last contacts of the limbs of Mercury and the Sun at  $0^{\text{h}}.8'.33''$  at Greenwich. The same was observed at Paris by M. Maraldi and M. Cassini de Thury, and at Thury by Mr. Cassini, at  $0^{\text{h}}.18'.05''.5$  by a mean of the three observations. The difference of longitude therefore is  $9'.32''.5$ .

In the year 1743 the last internal contact of the limbs was observed by Mr. Graham in Fleetstreet at  $1^{\text{h}}.0'.42''$ , and by Dr. Bevis at Beaufort-Buildings in  
the

the Strand at  $1^{\text{h}}.0'.33''$ : or by a mean of both when reduced to the meridian of Greenwich at  $1^{\text{h}}.1'.04''$ .— The same was observed by the Abbé de la Caille, by Mess. Maraldi, Monnier, and Cassini the son, at Paris, and by Mr. Cassini at Thury: which observations, when reduced to the meridian of the Royal Observatory, give  $1^{\text{h}}.10'.15''.5$  for the time of the internal contact: the difference of meridians is therefore  $9'.12''.5$ . — By a mean of the observations of Mr. Graham and Dr. Bevis when reduced to Greenwich, the last external contact on the same day happened at  $1^{\text{h}}.2'.42''$ . and by a mean of the observations in France the same happened there at  $1^{\text{h}}.12'.10''$ . The difference of longitude therefore is  $9'.28''$ . N B. No observations were made of this transit at the Royal Observatory at Greenwich, on account of clouds.

In the year 1753 was another transit of Mercury, when the unfavourable state of the heavens a few seconds before the time of the internal contact prevented any observations from being made at Greenwich, as appears from a paper communicated to me by the executors of the late Dr. Bradley. Both contacts however were luckily very well observed, by Mr. Short, Dr. Bevis and Mr. Bird; by a mean of whose observations reduced to the meridian of Greenwich the internal contact happened at  $10^{\text{h}}.9'.37''.5$ . The same contact was observed by 13 observers at Paris, and was found not to happen sooner than  $10^{\text{h}}.18'.36''$ , nor later than  $10^{\text{h}}.19'.03''$ . But by a mean of all at  $10^{\text{h}}.18'.45''$ . The difference of meridians therefore is  $9'.07''.5$ . By a mean of the observations of Mr. Short, Dr. Bevis, Mr. Bird, Mr. Canton, and Mr. Siffon, all reduced to the meridian of Greenwich, the external contact

contact happened at  $10^{\text{h}}.12'.17'',5$ . and at the Royal Observatory, by a mean of all the observations at Paris, at  $10^{\text{h}}.21'.33''$ . The difference of longitude therefore is  $9'.15'',5$ . And if we take a mean of these 7 results, the Royal Observatory at Paris will be found to be  $9'.17'' \frac{1}{2}$  to the East of the Royal Observatory at Greenwich, a determination very nearly agreeing with that mentioned by Sir Isaac Newton, and which, I believe, was deduced from a comparison of Dr. Halley's and Mr. Cassini's observations.

The Abbé de la Caille, in his memoir on the parallax of the Moon, supposes the difference of meridians to be  $9'.17''$  tho' he has not mentioned from what authority he drew that conclusion. I shall therefore suppose the difference of meridians to be  $9'.17''$ . — The last *internal contact* was observed at Paris by Mr. de la Lande at  $20^{\text{h}}.28' 25''$  or  $26''$ ; at  $20^{\text{h}}.28'.26''$  by Father Clouet, and by Mr. Maraldi and Mr. Barros separately at  $20^{\text{h}}.28'.42'$ . Mr. Pingré, in a very curious memoir on the Sun's parallax already referred to, supposes the internal contact to have happened at Paris at  $20^{\text{h}}.28'.38''$ . I shall therefore make use of the Abbé de la Caille's observation at  $20^{\text{h}}.28'.37'' \frac{1}{2}$ .

The difference of meridians between Paris and Stockholm, says Mr. Wargentín, is  $1^{\text{h}}.2'.51''$  or  $52''$  at most. Mr. de la Lande from a comparison of 17 observations of the first satellite of Jupiter made from 1750 to 1759 and communicated to him by Mr. Wargentín, determines the difference of longitude to be  $1^{\text{h}}.3'.10''$ . And the Abbé de la Caille, in his memoir on the Moon's parallax, supposes it to be  $1^{\text{h}}.3'.13''$ . As these two last determinations agree so nearly together, I shall suppose Stockholm to be

$1^{\text{h}}.3'.10''$  to the East of Paris, and  $1^{\text{h}}.12'.27''$  to the East of Greenwich; and the last internal contact to have happened at  $21^{\text{h}}.30'.09''$ , 5, which is a mean between the observations of Mess. Wargentin and Klingensfiern.

The City of Cajaneburg in Sweden is  $38'.40''$  to the East of Stockholm, according to very late observations; and therefore Cajaneburg is  $1^{\text{h}}.51'.07''$  to the East of Greenwich. The 2d internal contact happened at  $22^{\text{h}}.7'.59''$ , when the error in writing down the minutes is corrected according to the instruction given in Philosophical Transactions, for 1761, p. 231. Indeed (supposing the longitude of Cajaneburg as above set down to be exact) it is very easy to prove that the error of one minute was made at the egress rather than at the ingress.

The City of Tobolski in Siberia (according to the observation of the end of the solar eclipse on June 3d by Mr. Chappe and Mr. Planmann at Cajaneburg and calculated by Mr. Pingré) is  $2^{\text{h}}.42'.11''$  to the East of Cajaneburg; and this determination is also confirmed by Mr. Wargentin's observation of the same phase. Tobolski therefore is  $4^{\text{h}}.33'.18''$  to the East of Greenwich: and I suppose Mr. Chappe to have observed the last internal contact at  $0^{\text{h}}.49'.23'' \frac{1}{2}$ , without making any allowance for the luminous ring which appeared round Venus in his telescope.

The Observatory at Upsal (according to Mr. Wargentin in the Philosophical Transactions) is  $1^{\text{h}}.1'.10''$  to the East of Paris, and is therefore  $1^{\text{h}}.10'.27''$  to the East of Greenwich. By taking a mean of the three observations made there, the internal contact happened at  $21^{\text{h}}.28'.06''$ .

Tornea°

Tornea° has been generally supposed to be  $1^{\text{h}}.27'30''$  to the East of Paris; but with this difference of meridians, the observations at Tornea°, tho' made by Mr. Hellant, a very excellent observer, will give a parallax of the Sun much less than the other observations made in high Northern latitudes. In order to settle the longitude of this place, I am of opinion that we may have recourse with safety, and without incurring the charge of reasoning in a circle, to the observation of the transit itself; I mean the observation of the internal contact at the ingress. Whether we suppose the Sun's parallax to be  $8''$  or  $10''$ , the first internal contact would have happened sooner at Tornea° than at Stockholm  $19''$  or  $24''$ . As the Sun's parallax will readily be allowed to be more than  $8''$ , I shall suppose the first internal contact to have happened  $21''$  sooner. Tornea° is therefore  $24'55''$  to the East of Stockholm, and consequently  $1^{\text{h}}.37'.22''$  to the East of Greenwich. I shall make use of Mr. Hellant's observation of the internal contact at  $21^{\text{h}}.54'.08''$  in preference to that of Mr. Lagerbom.

Abo, the capital of Finland, where Mr. Justander observed the last internal contact at  $21^{\text{h}}.45'.19''$  (when a correction is made in the minutes) is  $1^{\text{h}}.11'.29''$  to the East of Paris, and  $1^{\text{h}}.28'.34''$  to the East of Greenwich.

At Hernosand, which is  $1^{\text{h}}.11'.29''$  to the East of Greenwich, I shall suppose the 2d internal contact was observed at  $21^{\text{h}}.28'.52''$ , as published in the Philosophical Transactions by Mr. Short from the Swedish acts.

I find the Island of Rodrigues by comparing three observations of eclipses of Jupiter's satellites with

others made in England and at the Cape, to be  $4^{\text{h}}.12'.38''$  to the East of Greenwich: and this determination is exactly confirmed by Mr. Pingré's comparison of the same eclipses. The observation of the occultation of a fixt star gives the longitude  $6''$  or  $7''$  greater. In the Philosophical Transactions, and even in the former part of the volume of the Memoirs of the Academy of Sciences for 1761, we find the internal contact was observed at Rodrigues at  $0^{\text{h}}.34'.47''$ ; And yet in the memoire on the Sun's parallax it is said to have happened at  $0^{\text{h}}.36'.49''$ . Upon comparing this latter with the time by the clock, it should seem that Mr. Pingré had committed a mistake in subtracting the error of his clock instead of adding it. But he has no where mentioned any reason for this difference.

Göttingen, where the celebrated Mr. Mayer observed the first internal contact at  $20^{\text{h}}.58'.26''$  to the East of Paris is  $30' 16''$  or  $39' 33''$  to the East of Greenwich.

The Abbé de la Caille has placed Bologna  $36'.03''$  to the East of Paris: By comparing the observations of the transit of Mercury, I find, by a mean of three results agreeing very nearly together, that Bologna is  $45'.15''$  to the East of Greenwich. Mr. Zanotti observed there the 2d internal contact at  $21^{\text{h}}.04'.34''$ . But as he used a refracting telescope of  $2\frac{1}{2}$  feet, and as two other observers with telescopes of 10 and 22 feet saw the contact  $24''$  later, I shall suppose it to have happened at  $21^{\text{h}} 4' 58''$ .

At Florence, the internal contact was observed with a reflector of more than 4 feet at  $21^{\text{h}}.4'.28''$  by Father Ximenes. The longitude of this place is  $34' 48''$  to the East of Paris, according to the table in the Connoissance des Mouvements Celestes, or  $35'.58''$  according

according to the table in the *Elemens d'Astronomie* by Mr. Caffini. By taking a mean of both, Florence is  $44'.40''$  to the East of Greenwich.

The longitude of St. Peters at Rome is  $49'.54''$  according to the French Astronomers. The internal contact was observed to happen at  $21^h.09'.36''$ . But as it is not said where this observation was made, the longitude given above will be found to be somewhat inaccurate.

Observations were also made at Madrid and Lisbon; at the former, the internal contact happened at  $20^h.6'.56''$  apparent time: and at Lisbon at  $19^h.44'.26''$ . The longitude of Madrid, as given in the *Philosophical Transactions*, is certainly erroneous; being more than a minute and a half too little, if the observation of the transit can be depended upon. At Lisbon, the longitude of the place was not determined by Mr. Ciera, who observed the transit, when Mr. Pingré, from whom I have taken the observation, left it in his way from Rodrigues. From the best accounts that I can collect, particularly from the 385th number of the *Philosophical Transactions*, and from an account of some observations by Mr. Short, Lisbon is about  $36'.26''$  to the West of Greenwich.

Now in order to deduce the Sun's parallax from the observations related above, I proceeded in the following manner. Having subtracted the difference of longitude between Greenwich and the Cape  $= 1^h.13'.28''$  from  $21^h.39'.52''$  the mean of the observed times at the Cape, and compared the remainder with the observed time at Greenwich, I find that the internal contact was observed  $7'.24''$  later at the Cape than

than at Greenwich, on account of parallax. I then calculated what would be the effect of parallax at each place, supposing the Sun's parallax to be 9 seconds; and found that the time of the internal contact would be accelerated  $1'.16'',63$  at Greenwich, and retarded  $6'.31',09$  at the Cape: the whole effect of parallax therefore is  $7'.47'',72$ . But the difference in time, as found by observation, is only  $7'.24''$ : and therefore the difference by calculation is to the difference by observation, as the assumed parallax is to the true parallax on the day of the transit, which by this observation is  $8'',543$ . The parallax resulting from each observation will be found in the following table, which will be sufficiently explained by the foregoing example.

Places.	Difference of calculated times.	Difference of observed times.	Sun's parallax.
Greenwich - - - - -	7 47, 72	7 24	8, 543
Paris - - - - -	7 28, 40	7 03, 5	8, 494
Stockholm - - - - -	8 53, 72	8 41, 5	8, 712
Upsal - - - - -	9 01, 83	8 45	8, 727
Cajaneburg - - - - -	9 42, 30	9 32	8, 841
Tobolski - - - - -	10 29, 06	10 18, 5	8, 848
Tornea° - - - - -	9 48, 95	9 38	8, 832
Abo - - - - -	9 11, 16	8 59	8, 801
Hernofand - - - - -	9 21, 17	9 01	8, 676
Rodrigues - - - - -	3 19, 72	2 13	5, 993
Gottingen - - - - -	7 54, 36	7 31	8, 558
Bologna - - - - -	7 03, 31	6 41	8, 525
Florence - - - - -	6 57, 79	6 36	8, 536
Rome - - - - -	6 45, 16	6 41	8, 907
			Such



Such is the result of a comparison of the best observations made in places whose longitudes are as accurately ascertained as the present state of Astronomy will permit: by a mean of the whole, rejecting only the observation at Rodrigues, the Sun's parallax on the day of the transit is  $8',692$ . — I have excluded the comparison of the observation at Rodrigues, because the parallax resulting from it differs so considerably from the rest. If we suppose the internal contact to have really happened one minute sooner, through a mistake in writing down the observation, the parallax will then be  $8',697$ .

This observation made at Rodrigues, supposing it exact, will furnish another term wherewith to compare the several observations made in Europe. The Sun's parallax resulting from each observation may be seen in the following table.

Places.	Difference of calculated times.	Difference of observ'd times.	Sun's parallax.	Difference of observed times.	Sun's parallax.
Greenwich - - -	4 28, 00	5 11	10, 444	4 11	8, 429
Paris - - - - -	4 8, 98	4 50, 5	10, 500	3 50, 5	8, 332
Stockholm - - -	5 39, 00	6 28, 5	10, 314	5 28, 5	8, 721
Upsal - - - - -	5 42, 11	6 32	10, 312	5 32	8, 734
Cajaneburg - - -	6 22, 58	7 19	10, 327	6 19	8, 915
Tobolski - - - -	7 09, 34	8 05, 5	10, 177	7 05, 5	8, 919
Tornea° - - - -	6 29, 23	7 25	10, 289	6 25	8, 902
Abo - - - - -	5 51, 46	6 47	10, 422	5 47	8, 886
Hernofand - - -	6 01, 45	6 49	10, 183	5 49	8, 690
Gottingen - - -	4 34, 64	5 18	10, 421	4 18	8, 454
Bologna - - - -	3 43, 59	4 33	10, 787	3 33	8, 372
Florence - - - -	3 38, 07	4 23	10, 854	3 23	8, 449
Cape of Good Hope	3 19, 72	2 13	5, 993	3 13	8, 697

The mean of the whole, rejecting the comparison of the Cape, is  $10''\text{,}419$ ; supposing the internal contact to have happened at  $0^{\text{h}}\text{.}36'\text{.}49''$ . But if a mistake of one minute was really committed, the 3d column will receive a considerable alteration and the parallax resulting from each observation will be represented in the last column, the mean of which is  $8''\text{,}654$ , agreeing as nearly as possible with the parallax resulting from all the best observations compared with the Cape.

Mr. Pingre finding the parallax resulting from his own observation to differ so widely from that deduced from the Cape, and that both observations might be made to agree by supposing an error of one minute in the observation at Rodrigues, has examined every source of error that might be committed; and upon the whole sees reason to prefer his own observation to that of Mr. Mason, *not because he could find no mistake in his own, but because he has proved that no mistake could possibly be committed.* His observation indeed is in some measure confirmed by comparing all the observations with that at Lisbon: from which comparison if the longitude above laid down may be depended upon, the Sun's parallax is somewhat more than 10 seconds.

The several observations, that have been compared with the observations both of the Cape and Rodrigues, may also be compared together; and by combining some of them, we may obtain different results, upon which we may more or less depend, as the differences between the observed times are greater or less.

Places

Places compared.	Difference of calculated times.		Difference of observ'd times.		Sun's parallax.
	'	"	'	"	
Tobolski and Greenwich - - - -	2	41, 34	2	54, 5	9, 734
Tobolski and Paris - - - - -	3	0, 36	3	15	9, 736
Tobolski and Gottingen - - - -	2	34, 70	2	47, 5	9, 744
Tobolski and Stockholm - - - -	1	30, 34	1	37, 0	9, 663
Tobolski and Upsal - - - - -	1	27, 23	1	33, 5	9, 646
Tobolski and Bologna - - - - -	3	25, 75	3	37, 5	9, 513
Tobolski and Florence - - - - -	3	31, 27	3	42, 5	9, 525
Stockholm and Greenwich - - - -	1	11, 1	1	17, 5	9, 824
Stockholm and Paris - - - - -	1	30, 02	1	38, 0	9, 797
Stockholm and Bologna - - - - -	1	55, 41	2	00, 5	9, 396
Stockholm and Florence - - - - -	2	0, 93	2	05, 5	9, 340
Tornea° and Gottingen - - - - -	1	54, 59	2	07	9, 974
Tornea° and Paris - - - - -	2	20, 25	2	34, 5	9, 914
Tornea° and Greenwich - - - - -	2	1, 23	2	14	9, 948
Cajaneburg and Greenwich - - - -	1	54, 58	2	08	10, 054
Cajaneburg and Paris - - - - -	2	13, 6c	2	28, 5	10, 003
Cajaneburg and Gottingen - - - -	1	47, 94	2	01	10, 088
Cajaneburg and Florence - - - - -	2	44, 51	2	56	9, 628
Cajaneburg and Bologna - - - - -	2	38, 99	2	51	9, 679
Upsal and Paris - - - - -	1	33, 13	1	41, 5	9, 808
Upsal and Greenwich - - - - -	1	14, 11	1	21	9, 836
Hernofand and Paris - - - - -	1	52, 47	1	57, 5	9, 402
Hernofand and Greenwich - - - - -	1	33, 45	1	37	9, 342
Hernofand and Bologna - - - - -	2	17, 86	2	20	9, 139
Hernofand and Florence - - - - -	2	23, 38	2	25	9, 101
Abo and Paris - - - - -	1	42, 46	1	55, 5	10, 145
Abo and Greenwich - - - - -	1	23, 44	1	33	10, 031
Abo and Bologna - - - - -	2	07, 85	2	18	9, 714
Abo and Florence - - - - -	2	13, 37	2	23	9, 649
Tornea° and Bologna - - - - -	2	45, 64	2	57	9, 617
Tornea° and Florence - - - - -	2	51, 16	3	02	9, 569
Greenwich and Paris - - - - -	0	19, 02	0	20, 5	9, 700

The mean of the whole is 9'', 695.

It has been shewn that the parallax resulting from the total durations _____ is	} 9, 579
— from a comparison of the observation at Madrafs with those of Tobolski and Cajaneburg is _____	} 9, 763
— from a comparison of the observed, with a calculated, duration without parallax, is	} 9, 724
— from the least distance of the centers —	9, 920
— from the observations combined together is	9, 695

It can hardly be supposed that as such different methods give a parallax of the Sun on the day of the transit equal to  $9'',736$ , that this parallax should yet be only  $8,692$  as deduced from a comparison of the observations with the Cape, while the same observations compared with those of Rodrigues and Lisbon shew that the parallax exceeds 10 seconds. Let us therefore suppose that the observers at the Cape have set down their observation one minute too soon, tho' it must be confessed that the time of the duration at the egress cannot warrant such a correction, and that the time of the internal contact should have been observed at  $21^h.40'.52''$ ; the parallax, by taking a mean, will then be  $9'',732$ , exactly agreeing with a mean of all the other determinations. And in this Quantity of the Sun's parallax we must either acquiesce, or remain as ignorant of the true quantity of it as we were before, till we can have recourse to the next transit on June 3d 1769, when the planet Venus will again pass over the Sun's disk, having something more

more than 10 minutes of North latitude ; and will be so favourably circumstanced, that, if the errors in observing each contact do not exceed 4'' or 5'', the quantity of the Sun's parallax may be determined within less than  $\frac{1}{1000}$ <sup>th</sup> part of the whole : as the total duration, or the interval between the two internal contacts, will be found to be about 18 minutes longer at Tornea° than at Mexico. But the several circumstances of that transit must be the subject of a future paper. Let it suffice at present to observe that it will in part be visible to the inhabitants of this island, as Venus will be seen wholly entered upon the Sun's disk more than half an hour before the time of sun-set at Greenwich.