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**Astronomy.** — *"Mutual occultations and eclipses of the satellites of Jupiter in* 1908." By Prof. J. A. C. OUDEMANS.

SECOND PART. — ECLIPSES.

(Communicated in the meeting of October 27, 1906).

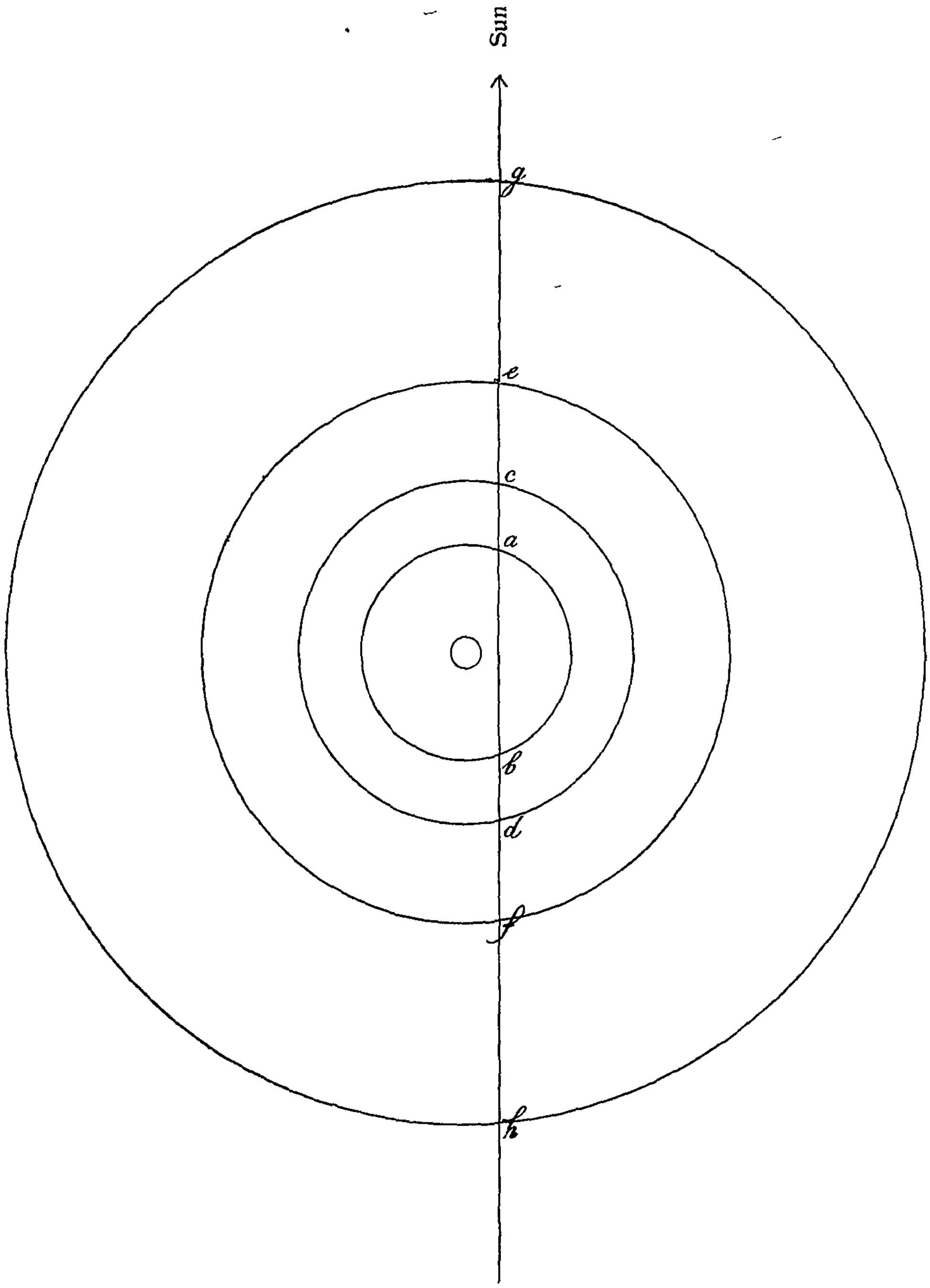
From occultations to eclipses there is but one step.

Between the two phenomena there is this difference that, as has been communicated on p. 305, the occultations have been observed more than once, but that of the eclipses of one satellite by another we have but one, incomplete account given in a private letter of Mr. STANLEY WILLIAMS dated 7 December 1905. In his letter to us he writes: "With regard to the heliocentric conjunctions there does "seem to be one observation of the rare phenomenon of the eclipse "of a satellite in the shadow of another one on record. It occurred "on the $14^{th}$ August 1891 and was observed by Mr. J. COMAS at "VALLS in Spain and by the writer at HOVE. Mr. COMAS' observation "was published in the FRENCH periodical L'Astronomie, 1891, p. 397 "(read 398) 1). The following is an account of my observation. No "particulars of this have hitherto been published."

" "1891 Aug. 14. $6^1/_2$ inch reflector, power 225. Definition good, " "but interruptions from cloud. Satellite I. transitted on the S. Equa- " "torial belt, (N. component). *Immediately* on its entering the disc " "it became lost to view. At $11^h49^m$ a minute dark spot was seen " "about in the position which the satellite should have then occupied. " "The shadows of satellites I. and II. were confounded together at " "this time, there seeming to be one very large, slightly oval, black " "spot. At $11^h59^m$ the two shadows were seen neatly separated, " "thus, ●• . The preceding shadow must be that of II., the follow- " "ing and *much smaller* one that of I.. At $12^h10^m$ satellite I. was " "certainly visible as a dark spot, much smaller than the shadow " "of either satellite. It had moved with respect to the shoulder of " "the Red Spot Hollow, so that there could be no doubt of its " "identity. It is on the north band of the north (south) equatorial " "belt 2). Satellite I [this should evidently be II.] shines brightly " "on the disc near the limb. Definition good, but much thin cloud " "about." "

"The foregoing is an almost literal transcript from my observation "book. I take it that when satellite I. entered on the disc of Jupiter, "it was already partly eclipsed by the shadow of II., so that it "became lost to view immediately, instead of shining, as usual, for

J. A. C. OUDEMANS. "Mutual occultations and eclipses of the satellites of Jupiter in 1908." Second part: Eclipses.




Scale $\frac{1}{30\,168\,000\,000}$. On this scale the sun's diameter is 0.24 meter and its distance 25.783 m.

"some time as a brillant disc. Also that the minute dark spot seen "at $11^h 49^m$ was produced by the portion of the shadow of II., then "projected on I. Also that the small size of the following shadow "spot at $11^h 59^m$ was due to a part only of the shadow of II. being "projected on the disc of Jupiter, the other part of this shadow "having been intercepted by satellite I. 3)

— — — "But combining Mr. Comas' observation with my own, "there can be no doubt but that satellite I. was actually partially "eclipsed by the shadow of II. on the night of August 14, 1891. "So far as I am aware, this is the only indubitable instance of one "satellite being eclipsed by the shadow of another."....

"P.S. The above times are Greenwich mean times. The Nautical "Almanac time for the transit ingress of satellite I. is $11^h 33^m$." 4).

Before proceeding to the computation of epochs of such heliocentric conjunctions we have investigated to what extent generally eclipses of one satellite by the shadow of another are possible. That they may occur is proved by the shadows of the satellites on Jupiter itself. The question however is: 1st whether the shadows of the foremost satellite reaches that of the more distant one in *every* heliocentric conjunction and 2nd whether the occurrence of total eclipses is possible in any case. In order to find an answer to these questions we assume that the orbits all lie in a single plane which, being prolonged, passes through the centre of the sun. We further imagine a line in the plane of the orbits starting from the sun and passing Jupiter at a distance equal to its radius, the distance from the centre thus being equal to its diameter (see Plate I). This line cuts the orbits of the four satellites each in two points. Beginning with the point nearest the sun we shall call these points *g*, *e*, *c*, *a*, *b*, *d*, *f* and *h*. For clearness, sake the figure is given below (Plate I).

Now suppose that I is placed either at *a* or at *b*. In both cases the other satellites will be involved in its shadow cone as soon as they come: $II_f$ at *d*, $III_f$ at *f* and $IV_f$ at *h*.

The points of intersection with the orbit of II are *c* and *d*. If $II_n$ is at *c* then $I_n$ may be eclipsed in *a* but also $I_f$ in *b*; $III_f$ at *f* and $IV_f$ at *h*.

But if $II_f$ is in *d* then only $III_f$ and $IV_f$ can be eclipsed, the former at *f* and the latter at *h*.

The points of intersection with the orbit of III are *e* and *f*. If III is at *e* there is the possibility of an eclipse for $II_n$ at *c*, $I_n$ at *a*, $I_f$ at *b*, $II_f$ at *d* and $IV_f$ at *h*. If on the other hand it is in *f* there is such a possibility only for $IV_f$ at *h*.

It is evident that IV can only cause the eclipse of another satellite if it is at the position $g$, one of the other three satellites being then at one of the points of intersection already mentioned.

Each of the satellites might thus produce six different eclipses; if, however we compute the radii of the umbra for the positions of the other satellites we are led to a negative value in some of the cases. This means of course that the vertex of the cone of the umbra does not reach the other satellite.

If, for the radii of the satellites we adopt the values mentioned in the first part of this communication, diminished however by the amount of the irradiation, it appears that a total eclipse is only possible in two cases. $III_n$ may cause a total eclipse of $II_n$ and $I_n$; $I_f$ may nearly produce such an eclipse of $II_f$. If the shadow does not reach the other satellite then an inhabitant of the latter would see an annular eclipse of the Sun.

This case presents itself

for the shadow of $I_n$ in respect to $IV_f$.
,, $II_n$ ,, ,, ,, $III_f$ and $IV_f$,
,, $III_n$ ,, ,, ,, $IV_f$,
,, $IV_n$ ,, ,, ,, $II_f$ and $III_f$.

In the fifteen remaining cases there may be a partial eclipse.

It need hardly be said that this case can only present itself if, at the time of heliocentric conjunction, the difference of the heliocentric latitudes $(y'—y)$, is smaller than the sum of the radii. In computing however the occultations observed by Messrs FAUTH and NIJLAND it appeared that this difference in latitude, according to the tables of DAMOISEAU, is sometimes slightly greater. The latitudes found by these tables are therefore not entirely trustworthy. For this reason we included *all* the heliocentric conjunctions between 1 April and 20 May 1908 (both dates inclusive).

The preparation for the computation, *viz* the drawing of the orbits of the satellites is the same as for the computation of the geocentric conjunctions (see 1st part). First however the epochs of the heliocentric superior conjunctions must be derived from the epochs of the *geocentric* superior conjunctions taken from the Nautical Almanac by the aid of the hourly motions of the satellites and of the angle $G$, i.e. the angle Earth—Jupiter—Sun. Furthermore, the jovicentric mean longitudes should be corrected for their equations and perturbations and diminished by S. i. e. the heliocentric longitude of Jupiter, instead of by S—G which is its geocentric longitude.

Of the arguments N°. 3 need not be computed; for this argument only serves, combined with 1, for the computation of the jovicentric latitude of the Earth, which need not be known in the present case. The number of columns in our tables will thus be found to be diminished by one for each of the satellites.

Our results are contained in the annexed table. Between 1 April and 20 May we found 81 heliocentric conjunctions; the last column but one, $(y-y')$, shows that in a very great number of the cases an eclipse is possible.

(1) The account of Mr. José Comas is as follows:

*Ombres de deux satellites de Jupiter et éclipse.* — Dans la nuit du 14 août, j'ai observé un phénomène bien rare: la coïncidence partielle, sur Jupiter, des ombres de ses deux premiers satellites, et par suite l'éclipse de Soleil pour le satellite I produit par le satellite II.

A $11^h$ (temps de Barcelone) [1]) l'ombre du satellite II est entrée sur la planète. Près du bord, elle n'était pas noire, mais d'un gris rougeâtre. Comme l'image était fort agitée, j'ai cessé d'observer, mais je suis retourné à l'observation vers $11^h37^m$ pour observer l'immersion du premier satellite, qui a eu lieu à $11^h42^m$ (grossissement 100 fois; lunette de 4 pouces). J'ai été surpris de voir disparaître Io [2]) à son entrée sur le disque, ne se détachant pas en blanc, quoiqu'il se projetât sur la bande foncée équatoriale australe.

A $11^h52^m$, avec des images plus tranquilles et un grossissement de 160, je remarquai que l'ombre complètement noire que l'on voyait était allongée dans une direction un peu inclinée vers la droite, relativement à l'axe de Jupiter. La phase maxima de l'éclipse du satellite I était déjà passée de quelques minutes. A $11^h56^m$ je pris le petit dessin que j'ai l'honneur de vous adresser; les deux ombres se touchaient encore [3]). Aussitôt elles se séparèrent et, quoique je n'aie pas pu noter l'instant du dernier contact, je crois être assez près de la vérité, en disant qu'il s'est effectué vers $11^h58^m$.

L'empiètement d'une ombre sur l'autre pourrait être de la troisième

[1]) Barcelone is 2°10' East of Greenwich; mean time at Barcelone is therefore $8^m40^s$ later than of Greenwich.

[2]) Since a few years the Nautical Almanac mentions the names of the Satellites of Jupiter proposed by Simon Marius: Io, Europa, Ganymedes and Callisto.

[3]) This drawing shows, as seen in an inverting telescope, the right hand (following) part of the well know Red spot in the Southern Hemisphere of Jupiter. Below it, at some distance, a dark band and still further two dark shadows each 4 mm. in diameter, which are not yet separated The common chord is 2,5 mm. in length; the total length of the two shadows together 7,2mm. The line connecting the centres makes an angle of 40° with the vertical. Meanwhile the motion of the two shadows must have been nearly horizontal.

partie du diamètre. Dans cette supposition la distance minima des centres des deux ombres a dû avoir lieu vers $11^h47^m$ et le premier contact vers $11^h37^m$. Le premier satellite pénétra dans le disque de la planète à $11^h42^m$, comme j'ai dit plus haut, donc l'éclipse a commencé quand le satellite se projetait encore dans l'espace, cinq minutes avant l'immersion.

L'invisibilité de l'ombre d'Europe sur Io peut s'expliquer par la mauvaise qualité des images. Toutefois, la pénombre et l'ombre du II satellite ont été suffisantes pour diminuer notablement l'éclat du premier.

(2) The meaning evidently is that, as seen in an *inverting* telescope the dark spot seemed to be situated on the North band of the North belt, but that in reality it was on the South band of the South belt. It is well known that the so-called *Red spot* is there situated.

(3) The author does not refer here to the visibility of a shadow of II on I. This may be explained, in my opinion, by irradiation and diffraction.

(4) According to the tables of DAMOISEAU, second part, the time of the heliocentric conjunction of the two satellites is $23^h45^m$ civil time Paris = $11^h36^m$ Greenwich. In the Nautical Almanac of 1891 we find the following data for 14 August:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| II | Shadow. | Ingress | $10^h51^m$ | M. | T. | Grw. |
| I | ,, | ,, | 10 59 | ,, | ,, | ,, |
| I | Transit | ,, | 11 33 | ,, | ,, | ,, |
| II | ,, | ,, | 11 58 | ,, | ,, | ,, |
| I | Shadow. | Egress | 13 18 | ,, | ,, | ,, |
| II | ,, | ,, | 13 45 | ,, | ,, | ,, |
| I | Transit | ,, | 13 51 | ,, | ,, | ,, |
| II | ,, | ,, | 14 49 | ,, | ,, | ,, |

If from the 1st, 2nd, 5th and 6th line we compute the time at which the shadows must coincide we get $11^h31^m$. This result differs by $5^m$ from that found just now. We have to consider, however, that the two satellites went the same way, and that their relative motion in five minutes, consequently also that of their shadows, was very minute.

Mr. STANLEY WILLIAMS seems not to have perceived a shadow before $11^h49^m$ M. T. Greenwich; Mr. COMAS already saw an oblong shadow at $11^h43^m20^s$ M. T. Greenwich. For the rest Mr. STANLEY

WILLIAMS makes the shadow of II larger than that of I whereas in the estimation of Mr. COMAS they were equal. It seems hardly doubtful but the English observer must be right.

(5) In 1901 SEE repeatedly measured the diameters of the satellites of Jupiter at the 26 inch telescope of Washington. He made use of the filar micrometer but took a special care to eliminate the systematic errors peculiar to this instrument (*Vid.* Astron. Nachr. N°. 3764, 21 Jan. 1902. The communication of SEE is dated 19 Oct. 1901).

During the months May—August (both inclusive) of the year 1901 he measured the diameters in the night. He was then much troubled by the undulation of the limbs caused by the unsteadiness of the air. Afterwards in the months of September and October of the same year he observed a little before and a little after sunset. Artificial illumination was then not needed; and the satellites appeared as quiet discs. Moreover the field and the satellites were coloured greenish yellow by a screen filled with protochloride of copper and picric acid. The results for the diameters turned out to be smaller in every case than those formerly found. The difference was attributed to irradiation.

The results, reduced to the mean distance of Jupiter to the sun (5,2028), are as follows.

| Satellite | At night | In daytime | Difference, attributed to irradiation |
|---|---|---|---|
| I | 1″,077 ± 0″018 | 0″834 ± 0″,006 | 0″243 ± 0″019 |
| II | 0 ,976 ± 0 ,043 | 0 ,747 ± 0 ,007 | 0 ,229 ± 0 ,0435 |
| III | 1 ,604 ± 0 ,038 | 1 ,265 ± 0 ,009 | 0 ,339 ± 0 ,039 |
| IV | 1 ,441 ± 0 ,018 | 1 ,169 ± 0 ,006 | 0 ,372 ± 0 ,019 |

It is remarkable that the brightest satellite, III, shows also the strongest irradiation. If however we consider the difference insufficiently established, and if therefore we combine the several results obtained for the irradiation, duly taking into account the weights corresponding to the probable errors, we get

$$\text{Irradiation} = 0'',264 \pm 0'',012.$$

This is the irradiation for the whole diameter and we thus get 0″,132 for each of the limbs. This number however holds only for the telescope at Washington for which, owing to its great aperture, the diffraction must be exceedingly small.

It seems worth while to call attention to the differences between the diameters found by the same observer in 1900 and 1901.

| | 1900 | 1901 | 1901—1900 |
|---|---|---|---|
| I | 0″672 ± 0″098 | 0″,834 ± 0″,006 | + 0″162 |
| II | 0,624 ± 0,078 | 0 ,747 ± 0 ,007 | + 0,121 |
| III | 1,361 ± 0,103 | 1 ,265 ± 0 ,009 | — 0,096 |
| IV | 1,277 ± 0,083 | 1 ,169 ± 0 ,006 | — 0,108 |

Stone, at Oxford, once told me that Airy, in a conversation on the determination of declinations at the meridian circle, remarked to him: "I assure you, Stone, a second is a very small thing".

If we consider the differences just adduced between the results obtained by a single observer in two consecutive years we are led to conclude that, for micrometer observations, even now "a tenth of a second is an exceedingly small thing".

Appendix. *In how far are the tables of* Damoiseau *still reliable?*

In the first part of this paper, pages 319 and 321, we explained why we felt ourselves justified in using the tables of Damoiseau for these computations in advance. We may now add that we also investigated the differences of the eclipses, as observed in some recent years at different observatories, from these tables, or rather from the epochs given by the Nautical Almanac. In these investigations we have been assisted by Mr Kress, amanuensis at the Observatory of Utrecht, who has carefully searched some volumes of the *Astronomische Nachrichten* and of the *Monthly Notices* for the time of "disappearance and reappearance" of each satellite. He has further combined these times, reduced them to the meridian of Greenwich, and has then compared them with the data of the Nautical Almanac. In order to simplify, we requested him to note only the observation of the last light seen at disappearance and the first light at reappearance[1]). We intended to extend our investigation from 1894 to 1905

[1]) Delambre in the introduction to his tables, does not state explicitly the *precise* instant to which his tables refer but from some passages we may conclude that he also means the instant *as here defined.* So for instance on page LIII where he says: *"Les demi-dureées ont été un peu diminuées, pour les rapprocher des observations qu'on a faites depuis la découverte des lunettes achromatiques".*

That Laplace also takes it for granted that such is his real meaning, appears from Ch. VIII, 8th book of the Mécanique Céleste.

or 1906, but after having completed some four years there seemed reason to think that there was hardly need for further information. The general result arrived at was, that the tables were still sufficiently accurate for our purpose, which was no other than to prepare astronomers for the observation of the mutual occultations and eclipses of the satellites.

Now that the work is finished we will not suppress its results though it cannot at all claim to be complete. It never was our intention to make it so, and the journals appearing in France, in America etc. have not been searched.

The following observatories have contributed to our investigation.

| | Aperture of the telescopes in m.m. |
|---|---|
| Greenwich | 102, 170, 254, 714. |
| Utrecht | 260 |
| Uccle | 150 |
| Jena (WINKLER) | 162 |
| Halifax (GLEDHILL) | 237 |
| Pola | 162 |
| Christiania | 74, 190 |
| Kasan | 66, 81, 84, 96, 244 |
| Gottingen | 161 |
| Windsor (Tebbutt) near Adelaide | 203 |
| Lyon (a single observation) | 2 |

At Greenwich, Christiania and Kasan the eclipses have been often observed by two or more astronomers using telescopes of different aperture. In such cases we have only taken into account the instant observed by means of the telescope of largest aperture. As a rule, the observer at this telescope could follow the satellite longer at "disappearance" and he would pick it up earlier at "reappearance". There are however a few exceptions to the rule.

For the eclipses observed during the period of a single opposition of Jupiter the corrections to the data of the Nautical Almanac in no case showed a regular progression. They fluctuated on both sides of the mean in such a way that there could be no objection to adopting their arithmetical mean, a proceeding which still would be perfectly justified, even if there had been a *regularly* increasing or decreasing progression. No further attention was paid to the differences in the aperture of the telescopes. If these apertures exceed a certain amount, for instance 150 mm. we find, theoretically as well as practically that the differences due to the varying apertures are very small.

The results arrived at are as follows:

Corrections to the epochs given in the Nautical Almanac for the eclipses of Jupiter's satellites.

| Opposition. | Mean Corr. N.A. Disapp. | Number. | Mean error. | Mean Corr. N.A. Reapp. | Number. | Mean error. | $\frac{1}{2}(D+R)$ | Mean error. |
|---|---|---|---|---|---|---|---|---|
| | | | | I. | | | | |
| 1894/95 | + $37^s$ | 3 | ±14 | — $18^s$ | 25 | ± $4^s$ | + $9^s.5$ | ± $7^s$ |
| 1895/96 | + 30 | 9 | 8 | 0 | 32 | 4 | + 15 | $4^5$ |
| 1897 | — $19^5$ | 2 | 18 | — 5 | 12 | 6 | — 12 | $9^5$ |
| 1898 | + 11 | 15 | 6 | + 7 | 13 | 6 | + 6 | 4 |
| | | | | II. | | | | |
| 9418 | — 78 | 2 | ±32 | 0 | 7 | ±$11^s$ | — $39^s$ | ±$17^s$ |
| 1894/95 | + 52 | 4 | $22^5$ | — 42 | 15 | $7^5$ | + 5 | 12 |
| 1895/96 | + 73 | 6 | 18 | — 4 | 19 | $6^5$ | + 34 | 10 |
| 1897 | — 72 | 3 | 26 | + 11 | 10 | 9 | — 30 | 14 |
| 1898 | — 36 | 5 | 20 | — 15 | 9 | $9^5$ | — 26 | 11 |
| | | | | III. | | | | |
| 1894 | +$151^s$ | 3 | ±$22^s$ | —$242^s$ | 3 | ±$38^s$ | — $45^s$ | ±$25^s$ |
| 1895 | +101 | 4 | 19 | —127 | 4 | 33 | — 13 | $11^5$ |
| 1895/96 | + 87 | 9 | 13 | — 50 | 9 | 22 | + 19 | $11^5$ |
| 1897 | +181 | 4 | 19 | + 37 | 9 | 22 | +109 | $14^5$ |
| 1898 | +266 | 4 | 19 | + 10 | 1 | 66 | +138 | 34 |
| 1899 | +361 | 3 | 22 | —126 | 4 | 33 | +118 | 20 |
| | | | | IV. | | | | |
| 1895 | + $21^m45^s$ | 3 | — | — $17^m\ 9^s$ | 2 | | +$138^s$ | |
| . . . | . . . . . | . . | . . | . . . . . | . . | . . | . . | . . |
| 1895/96 | + 3 49 | 10 | ±25 | — 3 17 | 7 | ±$22^s$ | + 16 | ±$17^s$ |
| 1897 | — 0 2 | 2 | ±57 | + 1 16 | 1 | 60 | + 37 | —41 |

Average mean error of a single observation.

| | Disappearance | Reappearance | Mean | Delambre *) Introd. p. LIV |
|---|---|---|---|---|
| I | ± 25s | ± 20s | ± 22s5 | 17s5 |
| II | 45 | 29 | 37 | |
| III | 37 | 66 | 51,5 | {88,5<br>72,5 rejecting the observations deviating more than 3 minutes). |
| IV | 80 | 60 | 70 | |

According to these numbers the complaints about the increased inaccuracy of the tables of DAMOISEAU seem rather exaggerated, at least for the first and second satellites.

Taking into account the mean errors contained in the last column we get the most probable correction at the epoch 1894—98

for I + $8^s$,0 with a mean error of ± $2^s$,6
similarly „ II — 3 ,8 „ „ „ „ „ ± 5 ,4.

Both corrections can hardly be vouched for.

For III the case stands otherwise. It is true, the subtractive correction at the reappearances as well as the additive one at the disappearances may be attributable to the use of more powerful telescopes; still there seems to be a progression in the numbers of the last column but one, which calls for a more exhaustive investigation.

In regard to IV, we found great corrections for the year 1895. After some years in which this satellite had not been eclipsed, owing to the fact that at the opposition it passed to the north of the shadow cone of Jupiter, there began a new period of eclipses in this year. In such a case the satellite travels high above the plane of the orbit of Jupiter, and describes only a small chord in the shadow. The consequence is that any small error in the latitude appears strongly magnified in the duration of the eclipse. The observations of Mr. WINKLER at Jena and of the observer at the observatory at Uccle near Brussels, of 8 March 1895 are very suggestive in this regard. The corrections were found to be:

| | Jena. | Brussels. | Mean |
|---|---|---|---|
| at disappearance | + $19^m 48^s$ | + $21^m 58^s$ | + $20^m 53^s$ |
| at reappearance | — 19 36 | — 18 33 | — 19 4,5 |

which shows that it is not the mean longitude of this satellite which is mainly in error.

*) DELAMBRE gives mean *differences*; we have multiplied his numbers by 1¼ in order to get mean *errors*.

The explanation of these extravagant differences must rather be sought, either in a correction needed by the longitude of the node of the satellite's orbit or in the adopted flattening of Jupiter. It is also possible that for suchlike eclipses the diminution of light is *very slow*.

For the rest, according to the Nautical Almanac, this eclipse would be the fourth after the long period in which no eclipse of this satellite occurred. The data, on pages 450, 452, 454 are as follows:

| | | | | |
|---|---|---|---|---|
| 1895 | | | | |
| 17 Jan$^y$. | D. $1^h\,36^m16^s$ M. T. Gr., | R. $2^h\,8^m17^s$, | duration | $32^m\;1^s$ |
| 2 Feb$^y$. | „ 19 26 12 „ „ „ | „ 20 36 58, | „ | $1^h$ 10 46 |
| 19 „ | „ 13 24 6 „ „ „ | „ 14 59 3, | „ | 1 34 57 |
| 8 March „ | 7 24 14 „ „ „ | „ 9 18 28, | „ | 1 54 14. |

Only, according to SCOTT-HANSEN, who, on the North-Polar expedition of NANSEN, was in charge of the astronomical observations, the satellite has not been eclipsed at all on the 17$^{th}$ of January [1]).

On the 2$^{nd}$ February 1895 too an eclipse of IV was not observed; (I cannot now call to mind where I saw this negative observation). On the 19$^{th}$ February, however, an observer at Greenwich, using the Sheephanks equatorial, aperture 120 mm., got a correction of $+\,23^m30^s$, for the disappearance of IV. This agrees quite well with the preceding results, obtained at Uccle and at Jena on 8$^{th}$ of March.

If we adopt the mean result of the observations at Brussels and at Jena, the duration of the eclipse on that day was

$$1^h44^m14^s - 39^m57^s{,}5 = 1^h14^m16^s{,}5,$$

The number might be of some use for the correction of the elements of IV.

The difference here found cannot be attributed to a too small value of the adopted flattening, for DAMOISEAU's value $\frac{1}{13{,}49}$ exceeds already that found by direct measurement by most observers. Taking into account however the results obtained by DE SITTER, as communicated at the meeting of the Section (Proceedings Vol. VIII p. 777), it appears that the longitude of the ascending node of the 4$^{th}$ satellite must be increased by about $+\,10°$, whereas for the inclination on

[1]) The Norwegian North Polar Expedition 1894 – 1896. Scientific Results, edited by FRIDTJOF NANSEN. VI. Astronomical Observations, arranged and reduced under the supervision of H. GEELMUYDEN, p. XXIV.

the fixed plane is found the value $= 0^\circ{,}2504 = 15' 2''4$, which exceeds DAMOISEAU's inclination only by somewhat less than a minute.

The remaining eclipses of IV in 1895 and the two following years do not show any extraordinary divergencies.

Now, as in 1908 the eclipses of the satellites will be nearly central, as may be gathered from the drawings in the Nautical Almanac accompanying the table of these phenomena, there is no need to fear that such great divergencies will occur for IV in that year.

Our result therefore is that the Nautical Almanac, which is based on the tables of DAMOISEAU (taking into account only a few necessary corrections), may be considered sufficient for preparing ourselves for the coming observations. The only exception would be for an early eclipse of IV after a period in which it is not eclipsed at all.

*Utrecht*, 23 November 1906.

# RESULTS.

## Mutual heliocentric conjunctions of the satellites in April and May 1908.

A.A. = Ann Arbor; Fl. = Flagstaff; H.K. = Hong Kong; La Pl. = La Plata; P. = Perth; Tac. = Tacubaja; To. = Tokio; We. = Wellington; Wi. = Windsor.

| No. | Mean time at Greenwich | n = near, f = far: Eclipsed satellite | Eclipsing satellite | $x=x'$ | Eclipsed satellite $y$ | Eclipsing satellite $y'$ | $y-y'$ | Visible at |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 April 4h 8m | $I_f$ | $II_n$ | +5r 70 | —0r 30 | —0r 25⁵ | —0r 04⁵ | Kas., Taschk., Madras, HK., Perth. |
| 2 | 2 » 18 3 | $I_f$ | $III_n$ | +3, 21 | —0, 16 | —0, 20 | +0,04 | Lick, Fl., Tac., AA., Harvard. |
| 3 | 3 » 4 15 | $II_f$ | $III_n$ | —2, 49 | +0, 08 | +0, 10 | —0,02 | Kas., Taschk., Madr., HK., Perth, To |
| 4 | 3 » 9 51 | $II_f$ | $I_n$ | +1, 50 | —0, 10⁵ | —0, 09 | —0,01⁵ | Grw., Pulk., Kas., Taschk., La Pl., Rio. |
| 5 | 3 » 11 10 | $IV_f$ | $III_n$ | —6, 19⁵ | +0, 40 | +0, 32 | +0,08 | Grw., Pulk., Kasan, La Pl., Rio. |
| 6 | 3 » 16 26 | $IV_f$ | $I_n$ | —4, 03 | +0, 30 | +0, 19 | +0,11 | Lick, Fl., Tac., AA., Harv., La Pl. |
| 7 | 4 » 16 52 | $IV_f$ | $II_n$ | +6, 03 | —0. 20 | —0, 27 | +0,07 | Lick, Fl., Tac., AA., Harvard. |
| 8 | 4 » 17 21 | $I_f$ | $II_n$ | +5, 75 | —0, 31 | —0, 25 | —0,06 | Lick, Fl., Tac., AA., Harvard. |
| 9 | 5 » 19 56 | $III_f$ | $II_n$ | —9, 24 | +0, 54 | +0, 30 | +0,24 | Wi., We., Lick, Fl., Tac., AA. |
| 10 | 6 » 20 12 | $III_f$ | $I_n$ | +3, 61 | —0, 18⁵ | —0, 21 | +0,02⁵ | Wi., We., Lick, Fl., Tac., AA. |
| 11 | 6 » 22 58 | $II_f$ | $I_n$ | +1, 37 | —0, 10 | —0, 09 | —0,01 | Perth, Tokio, Wi., We. |
| 12 | 8 » 6 31 | $I_{e.e.}$ | $II_n$ | +5, 82 | —0, 31 | —0, 25 | —0,06 | Bresl., Pulk., Kas., Taschk., Madras. |
| 13 | 9 » 20 52 | $I_f$ | $III_n$ | +3, 85⁵ | —0, 18 | —0, 24 | +0,06 | Wi., We., Lick, Fl. |
| 14 | 10 » 7 28 | $II_f$ | $III_n$ | —2, 05⁵ | +0, 06 | +0, 09⁵ | —0,03⁵ | Grw., Pulk., Kas., Taschk., Madras. |
| 15 | 10 » 12 4 | $II_f$ | $I_n$ | +1, 24 | —0, 09 | —0, 08 | —0,01 | Grw., Pulk., Kas., Harv., La Pl., Rio. |
| 16 | 11 » 15 42<br>11 » smallest distance | II | IV | II +7, 87<br>IV +7, 96 | —0, 36 | —0, 48 | +0,12 | Lick, Fl., Tac., AA., Harv., La Pl., Rio |
| 17 | 11 » 19 43 | $I_{e.e.}$ | $II_n$ | +5, 88 | —0, 31⁵ | —0, 26 | —0,05⁵ | Wi., We., Lick, Fl., Tac., AA. |
| 18 | 11 » 20 24 | $I_{e.e}$ | $IV_n$ | +5, 99 | —0, 32 | —0, 38 | +0,06 | Wi., We., Lick, Fl, |
| 19 | 12 » 23 33 | $III_f$ | $II_{w.e.}$ | —9, 41 | +0, 54 | +0, 45 | +0,09 | Perth, HK., Tokio, Wi., We. |
| 20 | 13 » 3 57 | $III_f$ | $IV_n$ | —7, 35 | +0. 42 | +0, 27 | +0,15 | Kasan, Taschk., Madr., HK. |
| 21 | 13 » 23 22 | $III_f$ | $I_n$ | +2, 64 | —0, 16 | —0, 19 | +0,03 | HK., Perth, Tokio, Wi., We. |
| 22 | 14 » 1 11 | $II_f$ | $I_n$ | +1, 11 | —0, 09 | —0, 06 | —0,03 | HK., Perth, Tokio, Wi. |
| 23 | 15 » 8 57 | $I_{e.e.}$ | $II_n$ | +5, 93 | —0, 32 | —0, 26 | —0,06 | Grw., Pulk., Kas., Taschk., Rio. |
| 24 | 16 » 23 44 | $I_f$ | $III_n$ | +4, 45⁵ | —0, 23 | —0. 26 | +0,03 | HK., Pe., To., Wi., We. |
| 25 | 17 » 10 41 | $II_f$ | $III_n$ | —1, 61 | +0, 03 | +0, 08 | —0,05 | Grw., Pulk., Kasan, La Pl., Rio. |
| 26 | 17 » 14 17 | $II_f$ | $I_n$ | +0, 98 | —0, 09 | —0, 06 | —0,03 | Grw., Fl., Tac., AA., Harv., La Pl., Rio |
| 27 | 18 » 22 11 | $I_{e.e.}$ | $II_n$ | +5, 97 | —0, 32 | —0, 26 | —0,06 | Perth, To., Wi., We. |

| No. | Mean time at Greenwich | n = near f = far Eclipsed satellite | Eclipsing satellite | x—x' | Eclipsed satellite y | Eclipsing satellite y | y—y' | Visible at |
|---|---|---|---|---|---|---|---|---|
| 28 | 19 April 5h15m | IV f | III w.e. | — 15r28 | + 0r80 | + 0r85 | — 0r05 | Kasan, Taschk., Madras. |
| 29 | 19 » 22 57 | IV f | II n | — 8,69 | + 0,48 | + 0,43 | + 0,05 | HK., Perth, Tokio, Wi., We. |
| 30 | 20 » 3 14 | III f | II n | — 9,54 | + 0,55 | + 0,45 | + 0,10 | Taschk., Madras, HK., Perth, T |
| 31 | 21 » 1 45 | III f | I n w.e. | + 2,27 | — 0,12 | — 0,13 | + 0,01 | Madras, HK., P., Tokio. |
| 32 | 21 » 1 46 | IV f | I n | + 2,26 | — 0,05 | — 0,12 | + 0,07 | Madras, HK., P., Tokio. |
| 33 | 21 » 1 52 | IV f | III f | + 2,33 | — 0,05 | — 0,12 | + 0,07 | Madras, HK., P., Tokio. |
| 34 | 21 » 3 23 | II f | I n | + 0,845 | —0,088 | — 0,044 | — 0,044 | Taschk., Madr., HK., P., Tokio. |
| | 22 » 12 19 | IV f | II f | + 6,62 | — 0,39 | — 0,44 | + 0,05 | Grw., Pulk., Harv., La Pl., Rio. |
| 35 | 22 » 15 13 | id. gr. | dist. | 8,01 and 7.84 | — 0.32 | — 0,40 | + 0,08 | Lick, Fl., Tac., A.A., Harv., La P |
| | 22 » 17 56 | » | » | + 8,88 | — 0,38 | — 0,44 | + 0,06 | We., Lick., Fl., Tac., A.A., Har |
| 36 | 22 » 9 41 | IV f | III (o.e.) | + 14,84 | — 0,66 | — 0,83 | + 0,17 | Grw., Pulk, Kasan, La Pl., Rio. |
| 37 | 22 » 11 27 | I (e.e.) | II n | + 6,01 | — 0,32 | — 0,26 | — 0,06 | Grw., Pulk., (Kasan), La Pl., Rio. |
| 38 | 24 » 2 41 | I f | III n | + 5,02 | — 0,255 | — 0,28 | + 0,025 | Taschk., Madr., HK., P., To. |
| 39 | 26 » 0 41 | I e.e. | II n | + 6,03 | — 0,33 | — 0,25 | — 0,08 | HK., P., To., Wi. |
| 40 | 27 » 7 5 | III f | II f | — 9,62 | + 0,54 | + 0,45 | + 0,09 | Bresl., Pulk., Kasan, Taschk. |
| 41 | 28 » 4 28[5] | I f | III n | + 1,57 | — 0,08 | — 0,09 | + 0,01 | Kasan, Taschk., Madr., HK. |
| 42 | 28 » 5 36 | II f | I n | + 0,58 | — 0,03 | — 0,065 | + 0,035 | Kasan, Taschk., Madras. |
| 43 | 28 » 13 29 | IV f | III n | + 6,41 | — 0,36 | — 0,36 | 0,00 | Grw., Tac., AA., Harv., La Pl., Rio |
| 43* | 28 » 16 18 | II | III | II + 7,31 III + 7,80 | — 0,38 | — 0,49 | + 0,06 | |

x—x' diminishes gradually in absolute value, reaches its minimum 0,49 at the time assigned and then increases again. So there is no eclipse.

| No. | Mean time at Greenwich | Eclipsed satellite | Eclipsing satellite | x—x' | Eclipsed satellite y | Eclipsing satellite y | y—y' | Visible at |
|---|---|---|---|---|---|---|---|---|
| 44 | 29 » 3 45 | I f | IV n | + 0,27 | — 0,02 | — 0,08 | + 0,08 | Taschk., Madr., HK. |
| 45 | 29 » 13 57 | I e.e. | II n | + 6,05 | — 0,33 | — 0,26 | — 0,07 | Tac., AA., Harv., La Pl., Rio. |
| 46 | 1 May 17 5 | II f | III n | — 0,74 | — 0,01 | — 0,62 | + 0,61 | Lick, Fl., Tac., AA., Harv., La Pl |
| 47 | 1 » 18 43 | II f | I n | + 0,44 | — 0,07 | — 0,02 | — 0,05 | Lick, Fl., Tac., AA. |
| 48 | 3 » 3 16 | I e.e. | II n | + 6,06 | — 0,32[5] | — 0,24 | — 0,08[5] | Taschk., Madr., HK., P., Tokio. |
| 49 | 4 » 11 7 | III f | II w.e. | — 9,61 | + 0,54 | + 0,45 | + 0,09 | Grw., Pulkowa. |
| 50 | 5 » 7 48 | II f | I n | + 0,31 | — 0,07 | — 0,02 | — 0,05 | Grw., Pulk., Kasan, Taschk. |
| 51 | 5 » 8 17 | III f | I n | — 0,10 | — 0,09 | — 0,01 | — 0,08 | Grw., Pulk., Kasan, (Taschk.). |
| | 5 » 14 2 | III f | II f | + 4,63 | — 0,26 | — 0,26 | 0,00 | Tac., A.A., Harv., La Pl., Rio. |
| 52 | 5 » 17 57 | greatest | dist. | +6,64 + 6,85 | — 0 38 | — 0,36 | + 0,02 | We., Lick, Fl., Tac., AA. |
| | 5 » 21 39 | III f | II f | + 8,43 | — 0,42 | — 0,49 | + 0,07 | To., Wi., We., Lick. |

| No. | Mean time at Greenwich | $n$ = near, $f$ = far: Eclipsed satellite | Eclipsing satellite | $x = x'$ | Eclipsed satellite $y$ | Eclipsing satellite $y'$ | $y - y'$ | Visible at |
|---|---|---|---|---|---|---|---|---|
| 53 | 6 » 16h38m | $I_{e,e}$ | $II_n$ | + 6,03 | − 0,215 | − 0,24 | + 0,025 | L ck., Fl., Tac, AA., Harvard. |
| 54 | 7 » 6 27 | $IV_n$ | $I_n$ | − 3,27 | + 0,20 | + 0,18 | + 0,02 | Bresl. Pulk, Kasan, Taschk., Madr. |
| 55 | 7 Mei 6 37 5 | $IV_n$ | $II_n$ | − 3,18 | + 0,19 | + 0,20 | − 0,01 | Bresl. Pulk., Kasan, Taschk, Madr. |
| 56 | 8 » 7 4 | $IV_f$ | $III_n$ | + 6,90 | − 0,38 | − 0,29 | − 0,09 | Bresl., Pulk., Kasan, Taschk., Madr. |
| 57 | 8 » 20 54 | $II_f$ | $I_n$ | + 0,18 | − 0,06 | − 0,00 | − 0,06 | Wi., Wellington. |
| 58 | 8 » 23 25 | $I_n$ | $III_n$ | − 2,04 | + 0,12 | + 0,13 | − 0,01 | Perth, Tokio, Windsor. |
| 59 | 9 » 5 29 | $I_{w.e.}$ | $III_n$ | − 5,36 | + 0,32 | + 0,34 | − 0,02 | Kasan, Taschk., Madras. |
| 60 | 10 » 6 0 | $I_n$ (e e) | $II_n$ | + 5,99 | − 0 32 | − 0,38 | + 0,06 | Kasan, Taschk., Madras. |
| 61 | 10 » 16 41 | $I_n$ | $II_n$ | − 0,97 | + 0,05 | + 0,10 | − 0,05 | Lick., Fl., Tac., AA., Harvard. |
| 62 | 11 » 0 13 | $I_n$ | $II_n$ | − 5,80 | + 0,32 | + 0,32 | 0,00 | HK., P., Tokio. |
| 63 | 11 » 15 26 | $III_f$ | $II_{w\,e}$ | − 9,46 | + 0,25 | + 0,43 | − 0,18 | Lick., Fl., Tac., AA., Harvard. |
| 64 | 12 » 9 54 | $III_f$ | $I_n$ | + 0,14 | − 0,03 | + 0,01 | − 0,04 | Grw., Pulk., Kasan, La Pl, Rio. |
| 65 | 12 » 10 0 | $II_f$ | $I_n$ | + 0,04 | − 0,38 | + 0,12 | − 0,50 | Grw., Pulk., Kasan, La Pl., Rio. |
| 66 | 12 » 10 41 | $III_f$ | $II_f$ | + 0,58 | − 0,10 | − 0,13 | + 0,03 | Grw., Pulk., La Pl., Rio. |
| 67 | 13 » 3 38 | $III_f$ | $II_f$ | + 9,32 | − 0,55 | − 0,45 | − 0,10 | Taschk., Madr., HK. |
| 68 | 13 » 19 31 | $I_n$ | $II_n$ | + 5,89 | − 0,33 | − 0,25 | − 0,08 | We., Lick., Fl. |
| 69 | 14 » 4 29 | $I_n$ | $II_n$ | + 0,10 | − 0,05 | + 0,02 | − 0,07 | Taschk., Madras. |
| 70 | 14 » 8 57 | $III_n$ (e e) | $IV_n$ | + 15 17 | − 0,87 | − 0,75 | − 0,12 | Grw., Pulk., Rio. |
| 71 | 14 » 13 46 | I(w e) | $II_n$ | − 5,93 | + 0,32 | + 0,33 | − 0 01 | Tac., AA., Harv., La Pl., Rio. |
| 72 | 15 » 9 48 | $I_f$ | $IV_n$ | + 5 59 | − 0,32 | − 0,29 | − 0,03 | Grw., Pulk., Kasan, La Pl, Rio. |
| 73 | 15 » 22 59 | $II_f$ | $IV_f$ | − 0 18 | − 0,06 | − 0,02 | − 0,04 | Perth, To., Wi. |
| 74 | 15 » 23 7 | $II_f$ | $I_n$ | − 0,09 | − 0,06 | + 0,02 | − 0,08 | Perth, To, Wi. |
| 75 | 16 » 11 59 | $I_f$ | $IV_n$ | − 5,69 | + 0,30 | + 0,24 | − 0,54 | Grw., La Pl., Rio. |
| 76 | 17 » 9 4 | $I_n$ | $II_n$ | + 5,75 | − 0,31 | − 0,23 | − 0,08 | Grw, Pulk., Kasan, La Pl., Rio. |
| 77 | 17 » 11 22 | $III_n$ (w,e) | $IV_n$ | − 14,82 | + 0,80 | + 0,70 | + 0,10 | Grw, Pulk., La Pl., Rio. |
| 78 | 17 » 16 9 | $I_n$ | $II_n$ | + 1,22 | − 0,085 | − 0,02 | − 0,065 | Lick, Fl, Tac., AA., Harvard. |
| 79 | 18 » 3 12 | I(w.e.) | $II_n$ | − 6,00 | + 0,32 | + 0,32 | 0,00 | Taschk., Madras, HK. |
| 80 | 18 » 20 36 | $III_f$ | $II_f$ | − 8,935 | + 0,51 | + 0,41 | + 0,10 | Wi., Wellington. |
| 81 | 20 » 8 8 | $III_f$ | $II_f$ | + 9,57 | − 0,56 | − 0,45 | − 0,11 | Grw., Pulk., Kasan. |

J. A. C. OUDEMANS "Mutual occultations and eclipses of the satellites of Jupiter in 1908." Second part: eclipses.

N B. The continuous circles show the contour of the satellites, the dotted circles represent the penumbra.

Scale 1 : 314 250 000. 12mm = 1" heliocentric.