EARLY OBSERVATIONS OF THE ELLIPTICAL DISKS OF JUPITER'S SATELLITES

BY WILLIAM H. PICKERING

THE phenomena presented by these interesting bodies, although fully described in the last century, are not yet as generally known and understood as they should be. A brief general description, therefore, may properly be given in this place, before proceeding to describe the observations themselves. The satellites, to begin with, as is clearly indicated by their small densities, probably are not solid bodies, but appear to be concentrated meteor swarms, or heaps of dust, like Saturn's rings. Their density in general slightly exceeds that of water. The fourth may be a little less, and the third perhaps as much as twice as great. In shape they appear to be prolate spheroids, their major axes exceeding the two minor ones by about ten per cent. In diameter they range from $0''.9$ to $1''.4$, and the ellipticity of their disks is therefore readily recognized at a glance, when seen under favorable circumstances. All four appear to revolve on their minor axes, the innermost one in $11^h\ 55^m$, the others in periods still unknown. The axis of rotation of the inner one is nearly, but not quite, perpendicular to its orbit, while the axes of the three outer ones are less inclined to that plane. Their elongations, therefore, always occur in different position angles from that of the first.

The phenomena they present are very similar to that of a close telescopic binary, excepting that the revolution is completed in a period of a few hours instead of several years. That they are interesting objects to watch may readily be conceded, especially when it is stated that the changes they exhibit are often visible in the course of a few minutes. This is particularly true of Satellite I at the time that it presents the circular phase. Its rotation is very swift, and the satellite is large enough, so that the rapid change in its appearance may be quickly detected.

The importance of the observations probably lies, however, not in their relation to these minute bodies themselves, but rather in their application to the general

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laws of the mechanics of rapidly rotating ellipsoids, with especial application to the study of the evolution of spectroscopic binaries.

It appears at first sight rather difficult to understand why so little interest has been taken hitherto in changes which one might naturally suppose would interest astronomers in general, whether observers or mathematicians. This is the more striking when it is known that the phenomena are readily visible with a 5-inch telescope, can be seen with one of 4 inches aperture, have indeed been independently discovered by over a dozen different astronomers, working in as many different observatories, and have been confirmed by as many more.

The explanation, however, is not far to seek, and is the same as that which applies to the canals of Mars, only recently generally accepted, and to the rather conspicuous, continuous, physical changes occurring on the Moon, not generally accepted at all as yet. Good atmospheric conditions are required for the observations, and these occur only at long intervals at the northern observatories, while the best conditions, when the phenomena are conspicuous at a glance, never occur there at all. Moreover the idea is not yet rooted out among astronomers in general, that, because a very large telescope will separate a double star which it is theoretically impossible for a smaller instrument to do anything more than elongate, the large telescope will therefore show everything else to more advantage than the smaller one. They forget that bad seeing affects the large instrument much more than it does the small one, and also, in the particular case of Jupiter's satellites, that there is the added difficulty with the large objective, that it gives far too much light to enable one to distinguish the shapes of the satellites clearly. Since the very largest telescopes only show the phenomenon with difficulty, and since moderate sized ones in the north show it only on rare occasions, astronomers have been led to believe that those who observe it regularly, and continuously are the victims of self illusion. It is hoped that the publication of the following somewhat prolonged series of observations may do something to combat this error.

The observations of Satellite I, which are two to three times as numerous as those of all the others put together, are here omitted for lack of space. This is less to be regretted since its period is accurately known, although some other quantities, such as the inclination of its axis, and its precession period, will have to be discussed in a later publication. The observation of these bodies has now been continued, whenever the opportunity occurred, through a period of thirty years, beginning in 1892.

The first four series, extending to 1904, were made with different instruments and magnifications. The first were made in Arequipa with an aperture of 12.5 inches

(31.5 cm), and a power of 700 diameters. With a higher magnification, Satellite IV, on account of its faintness, becomes too difficult to measure. For a few of the earlier drawings magnification 450 was employed. About two hundred measures of the diameters were made with the micrometer, and these are summarized in Harvard Annals **61**, 73. They were checked by similar measures made on an artificial disk located at a distance of 11.25 miles (18 km.), situated well up on the side of one of the neighboring mountains, named Chachani, at an altitude of 16,600 feet (5060 meters). It was immediately shown that any measures of small disks, made with a filar micrometer, were subject to material systematic corrections, depending on the method of measurement employed, whether the micrometer threads were made to coincide approximately with the limbs of the satellites, the usual method, or whether both threads were placed to one side of the satellite. The latter method was found to give smaller accidental errors, but with both methods the systematic errors were large. These errors lay in opposite directions. With the latter method the measures gave too small a value of the diameter, by about 0″.3. With the usual method the results were too large, by about 0″.2 (H. A. **32**, 141). It was found also that the quality of the seeing materially influenced the result. With poor seeing smaller values were obtained; therefore, if the ordinary method of measurement was employed, and the seeing was sufficiently poor, the two corrections nearly balanced one another. Comparing our results with the uncorrected measures of some of the best American and European observers, it was found that for the two inner satellites there was very close agreement, deviation 0″.04, but for satellites III and IV the deviations were 0″.16 and 0″.11 respectively. In all cases our corrected results were smaller than the uncorrected mean values of the other observers.

Comparing our results taken from the sixth column of Table XV, Harvard Annales, **61**, 75, which are repeated in the second column of Table I below, with Michelson's results obtained at about the same time with an interferometer, at the Lick Observatory, given in the third column, we find a much better agreement. Assuming his values to be correct, the table illustrates the great gain in accuracy for micrometric measures obtained by comparison of the measures with those made of an artificial disk.

TABLE I

Satellite	P	M	P–M
	″	″	″
I	1.04	1.02	+0.02
II	0.94	0.94	0.00
III	1.42	1.37	+0.05
IV	1.29	1.31	−0.02

The second series of observations of the satellites was made at the Lowell Observatory in Flagstaff, Arizona, in 1894, with an 18-inch refractor (46 cm.), and a magnification of 860 diameters. This series has already been reduced and published by Professor Douglass in the Annals of the Lowell Observatory, **2**, 3–178. Early in this series the Scale of Ellipticities was devised, and described in Astronomy and Astro-Physics, **13**, 729, 1894, and thereafter nearly all the estimates of the elongation of the disks have been expressed in terms of this scale. The scale is represented in the Lowell Annals, **2**, 140. The surface detail of the satellites is very fully exhibited in this publication, which contains ninety-eight drawings of I, forty-five of II, one hundred twenty-eight of III, and thirty-seven of IV. Moreover, in the series of observations for 1895 by Professor Douglass, which is added to it, there are two drawings of I, one of II, fifteen of III, and six of IV, making a total of 332 independent drawings, and giving by far the most complete representation of the surfaces of these four minute bodies yet published.

The third series of observations was made at Mandeville, Jamaica, in 1901, with a 5-inch refractor (12.5 cm.) and a magnification of 300 diameters, which is the lowest that it is practicable to employ to advantage for this purpose with any telescope. The telescope was mounted on a portable stand, without position circle or micrometer. Position angles had therefore to be estimated.

The fourth series was made at the Lowe Observatory on Echo Mountain, California, in 1904, with a 16-inch refractor (41 cm.) and a magnification of 750 diameters.

The fifth and later series were made at the Harvard Station in Mandeville, Jamaica, with the 11-inch Draper refractor (28 cm.), and a magnification of 660 diameters, beginning in 1912. Series of observations have been obtained at nearly every apparition since that time.

Detail has probably been detected on all of the satellites. It is much more readily seen on III, however, than on any of the others. With a 12-inch (30 cm.) aperture, a small dark spot due to diffraction is readily visible, with good seeing, near the center of the disk. If the objective is not properly centered, the spot too becomes eccentric. It is analogous to the white spot that has been seen with small apertures on the disk of Mercury, when transiting the Sun. The spot appears only occasionally on IV, with a low power, since this satellite is very dark. It has never been seen on I or II, because they are too small. It makes fainter and genuine detail more difficult to detect, but when the satellite is in transit over the planet, the spot disappears. This fact, and the lack of contrast at such times with the dark sky, causes the detail to be much more clearly seen under these circumstances.

Satellite III sometimes appears gibbous, that is to say, not elliptical, but flattened on one side. That side of the disk then usually appears slightly darker than the other. The appearance is characteristic of this satellite, and is not due to phase. Its cause is unknown.

The genuine detail of III, besides this peculiar shading, consists of a belt, sometimes forked, occasionally multiple, and more or less perpendicular to the major axis of the disk. Occasionally a similar dark equatorial belt, or a bright polar spot, has been detected on IV without much difficulty, but usually the detail on I is easier, although always difficult. It seems to consist of a dark narrow belt nearly coinciding with the minor axis. It is not complete, however, and appears frequently extending only part way across the disk. Sometimes it is on one side, and sometimes on the other, of the major axis. It is usually visible only for short intervals.

When Jupiter is in opposition, the shape of the shadow of a satellite appears exactly the same as the body casting it, no matter on what portion of the disk of the planet it may fall. It has sometimes been suggested that the apparent changes in shape of the satellites were due to invisible dark detail upon their surfaces. To anyone who has seen the satellites under favorable conditions, such an explanation appears preposterous, first because the detail visible is not of a character to produce such an effect, second because the disk is not at all vague, but is clearly seen as an ellipse, and third because in the case of at least one satellite, namely I, its shadow has been several times observed in transit at opposition, and is then clearly elliptical, and lies in the same position angle as the satellite which casts it.

It is most important, in order to secure accurate results in observing, that the observer's position should be perfectly comfortable, and that he should be relieved of all strain. In some of the observations, especially those made at Flagstaff and in California, as a precaution to avoid systematic error, the head was so turned as to place the line joining the observer's eyes either exactly parallel or exactly perpendicular to the direction of the major axis of the satellite. This produced considerable strain in some positions. The difficulty was later avoided by the use of a diagonal eye-piece. No observations should be made at an altitude of less than 35°, on account of inferior seeing, and the effect of differential refraction, which leads to irregular and varying results. Indeed, the nearer the planet is to the zenith the better.

Any astigmatism of the observer's eye should be corrected by spectacles. The magnification should always be the same throughout the series, regardless of the quality of the seeing. On poor nights it is useless to attempt to obtain satisfactory results. It is found to be more convenient in going from one satellite to another either to work without the clock, and permit the satellite to trail across the center of the field, or else to have the right ascension only lightly clamped, so that it can be easily changed. When working with a large telescope, if the seeing is found to deteriorate gradually, this may sometimes be remedied by careful refocusing. Care should always be taken to see that the dome does not cover any portion of the lens.

When very near Jupiter, a satellite often appears to shorten in a direction radial to the planet. Thus when nearly in contact with the limb, Satellite I sometimes appears nearly circular, whether it is on the nearer or the farther side of its orbit. As soon as it enters on the disk it becomes elongated, usually extremely so. This is doubtless due to a bright though otherwise scarcely visible whitish band extending parallel to its longer axis. A reduction of the observations shows that the satellite becomes circular at intervals of a little less than six hours, and that the apparently circular phase, before and after transit or occultation, does not coincide with this period, and is, in fact, merely a subjective phenomenon. The three outer satellites, notably II, shift their position angles when very near the planet, so that their longer axes appear to become nearly tangent to its limb.

It may in general be said that observations of the elongation of I, II, and IV are of little value if the seeing is inferior to 8, although a lengthening of their disks can be vaguely detected with seeing 7. Elongations of III are satisfactory with seeing 7, are of some use at 6, and can even be suspected at 5. Position angles require slightly better seeing than elongations.

FIRST SERIES. 1892, AREQUIPA

The fact that the disks of all four of the larger satellites of Jupiter, when seen under favorable circumstances, are at times obviously elliptical was first noticed by the writer at Arequipa in 1892 (Astronomy and Astro-Physics **12**, 193, 1893). It had been discovered for Satellites I, III, and IV by other observers previously, or at all events suspected by them, and a brief history of the successive discoveries is given in Harvard Annals **61**, 78. Owing to the writer's temporary absence from the observatory, his observations at this apparition were divided into two groups, the later ones being made with Jupiter at a rather low altitude, which would affect both the ellipticities and position angles. The observations are therefore less accurate than those of later years. Satellite I is nearly always elongated while the other three frequently appear circular.

The observations were begun October 7, and it was at once noticed that the belts of Jupiter and all the diverse markings upon its surface were due to a thin gauzy layer of brown cloud, overlying a perfectly white surface. The gauzy layer seems to be composed of an enormous number of minute clouds, each measuring only a few tenths of a second in length, and arranged parallel to the equator. Where these clouds are very numerous we have the belts, where they are more widely separated we have the intermediate spaces, and where there are none at all we have the minute white spots and streaks. The belts are therefore clearly above the bright regions. The observation was described at the time in Astronomy and Astro-Physics, **12**, 193, 1893, but although readily seen here at Mandeville, the existence of these minute clouds has as yet been confirmed by only two other observers, Messrs. Phillips and Stevenson, as far as the writer is aware. A number of drawings of the surface detail of the satellites were secured at this opposition. There were nine drawings of I, one of II, thirty-eight of III, and seven of IV, fifty-five in all.

The position angles, at first estimated, were later measured with a micrometer, but the Scale of Ellipticities had not at that time been devised, so that the elongations had in each case to be described in words.

In the successive columns of Table II are given the date, the Julian Day, and decimal, and the position angle of the major axis of the disk referred to Jupiter's axis, as determined by the position angle of his belts. The angles of the satellites were taken alternately in a positive and negative direction in order to eliminate subjective errors. The fourth and fifth columns give the average deviation and the number of readings for Satellites III and IV. The sixth column gives a description of the amount of the elongation, as follows:

1. Appears elongated. 2. Slightly elongated. 3. Certainly elongated. 4. Clearly elongated. 5. Distinctly elongated. 6. Very elongated. 7. Elongated equatorially. 8. Appears round. 9. Nearly round. 10. Round. 11. Magnification 1120, 1500, and 2100. 12. More elongated than Jupiter. 13. Less elongated than Jupiter. 14. As much as Jupiter. 15. Rounder than before. 16. Not very satisfactory. 17. Shortening slightly.

The seventh column gives the quality of the seeing reduced to the present scale of 12, and the last the initial of the observer, whether Professor Douglass or the writer. The opposition of Jupiter occurred on October 12.

TABLE II

Date	J. D. 2412	P. A.	Dev.	No.	Form	Seeing	Obs.
SATELLITE II							
1892							
Oct. 10	382.551	90	..	..	2	9	P
	.695	180	..	..	2	10	"
12	384.700	...	..	..	10	6	"
13	385.559	...	..	..	3	6	"
	.677	...	..	..	10	...	D
	.711	...	..	..	10	...	"
14	386.524	90	..	..	7	...	P
	.542	...	..	..	3,11	...	"
	.554	...	..	..	10	...	D
	.592	90	..	..	2	12	"
15	387.621	...	..	..	10	...	P
	.665	...	..	..	3	...	"
	.700	...	..	..	3	...	"
Nov. 18	421.582	...	..	..	10	...	"
22	425.521	...	..	..	12	...	"
	.638	...	..	..	13	...	"
26	429.649	...	..	..	9	6	"
27	430.584	...	..	..	3	...	"
28	431.627	...	..	..	10	6	"
29	432.469	...	..	..	2	10	"
	.473	...	..	..	9	10	"
	.559	...	..	..	10	...	"
Dec. 3	436.479	...	..	..	10	...	"
6	439.519	...	..	..	10	9	"
9	442.488	...	..	..	2	...	"
	.530	...	..	..	2	...	"
	.644	...	..	..	3	...	"
11	444.487	...	..	..	3	9	"
	.512	...	..	..	4	9	"
23	456.576	...	..	..	10	...	"
	.633	...	..	..	1	8	"
25	458.510	...	..	..	10	...	"
	.646	...	..	..	10	...	D
26	459.573	...	..	..	9	...	P
28	461.493	...	..	..	10	...	"
	.529	...	..	..	4	8	"
29	462.510	...	..	..	3	6	"
	.519	...	..	..	3	...	"
	.525	...	..	..	5	...	D
	.527	...	..	..	4	...	P
30	463.496	...	..	..	1	6	"
	.538	...	..	..	3	8	"
	.563	...	..	..	4	10	"
	.576	...	..	..	10	10	"
	.593	...	..	..	9	...	"
Dec. 31	464.501	...	..	..	2	...	P
	.521	...	..	..	8	6	"
	.524	...	..	..	9	8	"
	.531	...	..	..	10	6	"
	.535	...	..	..	10	6	"
	.545	...	..	..	9	...	"
	.547	...	..	..	9	...	"
	.570	...	..	..	10	...	"
	.607	...	..	..	10	10	"
1893							
Jan. 1	465.500	...	..	..	10	...	"
	.524	...	..	..	10	...	"
	.557	...	..	..	8	6	D
	.573	...	..	..	10	...	P
10	474.573	...	..	..	2	...	D
11	475.563	...	..	..	3	...	P
13	477.506	90	..	..	7	...	"
	.559	...	..	..	10	8	"
	.591	...	..	..	3	8	"
14	478.530	...	..	..	10	8	"
	.531	...	..	..	2	8	"
15	479.490	...	..	..	2	...	"
16	480.499	...	..	..	3	10	"
	.523	...	..	..	6	...	"
	.549	167.9	..	..	...	9	"
	.591	...	..	..	3	8	"
17	481.500	...	..	..	2	...	"
20	484.551	...	..	..	9	8	"
22	486.593	...	..	..	3	...	"
26	490.496	...	..	..	10	8	"
27	491.483	...	..	..	10	...	"
	.487	...	..	..	2	11	"
28	492.491	...	..	..	10	9	"
	.508	...	..	..	10	10	"
	.526	...	..	..	3	...	"
29	493.503	...	..	..	2	...	"
SATELLITE III							
1892							
Oct. 13	385.667	...	..	..	10	...	D
	.711	...	..	..	10	...	"
14	386.573	...	..	..	10	12	P
15	387.552	...	..	..	3	...	"
	.556	205.0	11.8	6	...	...	"

SATELLITE III

Date	J. D. 2412	P. A.	Dev.	No.	Form	Seeing	Obs.
1892							
Oct. 13	387.621	...	..	..	10	...	P
	.635	...	..	..	10	...	"
Nov. 29	432.479	...	..	..	10	...	"
	.577	...	..	..	10	...	"
Dec. 3	436.479	...	..	..	10	...	"
7	440.602	...	..	..	10	...	"
11	444.672	...	..	..	10	11	"
23	456.580	...	..	..	2	10	"
	.599	158.7	3.8	6	3	...	"
	.603	164.8	2.1	4	5	...	D
	.633	...	..	..	6	...	P
24	457.653	...	..	..	1	6	"
25	458.510	...	..	..	10	...	"
	.646	...	..	..	9	...	D
26	459.573	...	..	..	10	...	P
28	461.493	...	..	..	10	...	"
29	462.527	...	..	..	17	...	"
	.530	...	..	..	10	...	D
	.568	...	..	..	9	10	P
30	463.496	...	..	..	3	6	"
	.531	...	..	..	3	8	"
	.563	...	..	..	4	10	"
	.614	170	..	1	6	...	D
31	464.577	170.6	2.8	6	6	...	P
1893							
Jan. 1	465.500	174.4	6.9	2	2	...	"
	.576	171.2	1.8	2	...	...	D
10	474.524	...	..	..	3	9	"
	.531	...	..	..	1	...	P
11	475.563	...	..	..	3	10	"
12	476.517	...	..	..	10	10	"
	.518	...	..	..	10	10	"
13	477.508	...	..	..	2	...	"
	.559	...	..	..	4	8	"
	.566	...	..	..	5	8	"
	.581	161.9	1.3	6	...	...	"
	.591	...	..	..	5	8	"
14	478.528	...	..	..	4	...	"
	.530	...	..	..	6	...	"
	.561	175.9	1.5	6	...	10	"
15	479.490	...	..	..	3	...	"
	.503	168.4	4.0	6	...	10	"
	.568	168.6	4.6	6	15	9	"
16	480.499	...	..	..	10	...	"
	.523	...	..	..	3	...	"
	.591	...	..	..	10	8	"
	.597	...	..	..	10	8	"

SATELLITE III

Date	J. D. 2412	P. A.	Dev.	No.	Form	Seeing	Obs.
1893							
Jan. 17	481.500	...	..	..	2	...	P
19	483.604	...	..	..	10	6	"
22	486.593	...	..	..	4	...	"
26	490.496	...	..	..	10	7	"
27	491.564	...	..	..	2	10	"
	.566	...	..	..	10	...	"
28	492.491	...	..	..	10	9	"
	.510	...	..	..	12	11	"
29	493.503	...	..	..	3	...	"
	.530	174.2	4.2	6	...	...	"
	.549	172.1	2.4	6	...	...	D

SATELLITE IV

Date	J. D. 2412	P. A.	Dev.	No.	Form	Seeing	Obs.
1892							
Oct. 9	381.607	...	..	..	10	12	P
	.692	180	..	1	2	10	"
Nov. 28	431.578	...	..	..	2	...	"
29	432.477	...	..	..	9	10	"
	.567	...	..	..	10	12	"
Dec. 3	436.479	...	..	..	10	...	"
6	439.542	...	..	..	2	...	"
7	440.602	...	..	..	10	...	"
11	444.679	...	..	..	1	8	"
23	456.570	...	..	..	2	12	"
	.633	...	..	..	3	...	"
24	457.653	170.4	25.8	4	1	6	"
25	458.510	...	..	..	1	...	"
26	459.573	...	..	..	10	...	"
28	461.493	...	..	..	10	...	"
29	462.576	...	..	..	2	11	"
30	463.577	...	..	..	2	...	"
	.604	...	..	..	2	...	D
31	464.570	...	..	..	3	...	P
	.615	166.8	9.2	2	16	...	"
1893							
Jan. 1	465.500	...	..	..	1	...	P
11	475.563	...	..	..	1	...	"
12	476.521	...	..	..	10	12	"
13	477.510	...	..	..	10	...	"
	.559	...	..	..	10	8	"
	.592	...	..	..	3	8	"
14	478.528	...	..	..	4	...	"
	.543	185.9	4.4	6	...	...	"
15	479.490	...	..	..	3	8	"
16	480.523	...	..	..	9	9	"
	.591	...	..	..	10	8	"

SATELLITE IV								SATELLITE IV							
Date.	J. D. 2412	P. A.	Dev.	No.	Form	Seeing	Obs.	Date.	J. D. 2412	P. A.	Dev.	No.	Form	Seeing	Obs.
1893								**1893**							
Jan. 17	481.500	...	..	..	2	...	P	Jan. 27	491.483	...	..	..	10	11	P
19	483.604	...	..	..	10	6	"	28	492.491	...	..	..	14	10	"
20	484.552	...	..	..	10	8	"		.512	...	..	..	12	11	"
22	486.593	...	..	..	4	...	"	29	493.503	...	..	..	2	...	"
26	490.538	...	..	..	2	8	"								

THIRD SERIES. 1901, MANDEVILLE, JAMAICA

Since the observations of this series were made with an aperture of only 5 inches (12.5 cm.), and a magnification of but 300, it might at first sight be supposed that they would be of rather doubtful value. Such, however, does not seem to be the case, since with good seeing the elongations even of Satellites I and II were clearly seen. To put the matter to a test, Satellite I, under excellent seeing, was viewed with the full aperture, and the elongation was recorded as "easily seen." A 4-inch diaphragm was then placed over the objective, and the elongation recorded as "visible but not striking." With a 3-inch diaphragm one "could not be sure of the elongation." It is probable, however, that even with this aperture the elongation of Satellite III, when well marked, could be seen. It would appear therefore that the possessors of small telescopes, if located in favourable climates, need not be afraid to contribute their share to this subject, and may succeed in securing useful observations of bodies that are usually considered so difficult that even the possessors of some of the world's largest telescopes have pronounced the disks to be always circular. In short we may say that success depends chiefly on eyesight and climate, rather than on aperture. The position angles given in Table III were all estimated. No drawings of detail were attempted. The writer was assisted in these observations by Mr. E. R. Cram. The opposition of Jupiter occurred on June 30. Satellite IV is too faint to observe with this aperture.

TABLE III

SATELLITE II

1901		G. M. T.	2415	P. A.	Form	Seeing	Obs.
July	20	15 47	586.657	..	1.02	..	P
		15 54	.663	..	1.00	7	C
		15 58	.665	..	1.04	8	P
		16 05	.670	..	1.02	9	C
		16 10	.674	1.02	..	9	P
		16 22	.682	..	1.02	..	"
		16 33	.690	..	1.04	..	C
		16 40	.695	..	1.04	..	P
		17 51	.743	..	1.04	..	C
	21	15 23	587.641	..	1.00	..	"
	23	16 23	589.683	..	1.06	..	P
	28	15 54	594.663	90	1.05	9	"
		16 10	.674	..	1.05	..	"
		16 21	.681	200	1.03	..	C
		16 24	.684	90	1.05	..	P

SATELLITE III

1901		G. M. T.	2415	P. A.	Form	Seeing	Obs.
July	19	13 00	585.542	..	1.07	..	P
	20	15 37	586.651	..	1.02	..	"
		15 54	.663	..	1.00	7	C
		15 58	.665	..	1.03	8	P
		16 22	.682	..	1.04	..	"
		16 33	.690	..	1.00	..	C
		16 40	.695	..	1.04	..	P
		16 43	.697	..	1.00	..	C
		17 51	.743	..	1.00	..	"
	21	15 23	587.641	..	0.96	..	"
		15 48	.658	160	1.06	..	"
		15 50	.660	160	1.06	..	P
		17 48	.741	..	1.05	..	"
	22	15 24	588.642	170	1.10	..	"
		16 18	.679	..	1.08	..	"
		16 58	.707	170	1.09	..	"
	23	16 05	589.670	90	1.04	6	"
		16 50	.702	..	1.00	..	"
		17 08	.714	90	1.03	..	"
	24	15 39	590.652	180	1.04	..	"
		15 56	.664	..	1.03	..	"
		16 30	.688	210	1.07	..	C
		17 20	.722	200	1.04	..	"
	26	16 10	592.674	90	1.06	..	P
		16 23	.683	..	1.06	..	"
		16 25	.684	..	1.06	..	"
	27	14 12	593.591	240	1.06	..	"
July	27	14 27	593.602	225	1.05	..	P
		15 05	.628	100	0.95	..	C
		15 12	.633	190	1.05	..	P
		15 40	.653	190	1.05	..	"
	28	16 46	594.699	180	1.04	..	"
		16 50	.702	180	1.05	10	"
		16 55	.705	170	1.05	..	"
		18 20	.764	..	1.05	6	C
	31	14 55	597.621	..	0.97	..	"
Aug.	1	14 20	598.597	150	1.08	..	P
		16 58	.707	160	1.07	..	"
		17 32	.730	150	1.06	7	"
	2	13 45	599.573	110	1.04	8	"
		13 50	.577	..	1.04	8	"
		16 25	.684	100	1.05	..	"
	4	12 35	601.524	..	1.00	..	"
		14 00	.583	170	1.02	..	C
	5	14 13	602.593	165	1.11	..	P
		14 18	.595	160	1.11	..	"
	6	14 35	603.607	210	1.06	..	"
		14 57	.623	150	1.06	..	"
	7	14 52	604.619	210	1.02	..	"
		16 50	.702	200	1.02	..	"
	8	12 47	605.533	190	1.05	..	"
		12 59	.541	190	1.05	..	"
	9	14 05	606.586	..	1.00	6	"
	10	13 13	607.551	180	1.05	..	"
	11	14 07	608.588	180	1.06	..	"
	12	14 08	609.588	180	1.05	..	"
	13	14 54	610.621	180	1.04	..	"
	18	14 10	615.590	..	1.00	..	"
	22	12 35	619.524	..	1.00	..	"
		14 51	.618	180	1.04	4	"
		15 03	.627	205	1.06	6	C
	23	12 30	620.521	195	1.03	8,9	"
	28	16 19	625.680	170	1.03	..	"
	29	12 50	626.535	210	1.05	..	P
Sept.	4	14 53	632.620	..	1.00	..	"
		14 55	.621	180	1.02	..	"
		15 04	.628	180	1.04	..	"
	10	11 48	638.491	160	1.10	..	"
		12 00	.500	150	1.09	..	"
		13 56	.581	150	1.07	..	"
		14 12	.591	180	1.03	..	C
		14 32	.605	180	1.05	..	P
		14 35	.607	180	1.05	..	"

FOURTH SERIES. 1904, CALIFORNIA

These observations were made in July, August, and September, at the Lowe Observatory on Echo Mountain, near Pasadena, California. We employed a 16-inch (41 cm.) refractor by Clark, and a magnification of 750. A number of drawings showing detail were made. There were 21 of I, 5 of II, 31 of III, and 4 of IV, 61 in all. All of the observations were made by the writer. It was found that when the line joining the two eyes was placed perpendicular to the major axis of the satellite, the ellipticity in the case of Satellite I measured about 4 per cent greater than when it was parallel to it. Both eyes gave practically identical results. In the seventh column of Table IV, r stands for perpendicular and l for parallel. Opposition occurred upon October 18.

CAMBRIDGE OBSERVATIONS

A series of observations of Satellite III was made in Cambridge on some fifty nights between October 1, 1904 and March 23, 1905. The 6-inch and 15-inch refractors were employed. On three-quarters of the nights elongations of the disk were suspected, and on about half of them position angles were estimated. It is doubtful if any of these results are of much value however, on account of the poor seeing that prevails at Cambridge, and they have in consequence all been rejected. No attempt was made to secure observations of the three more difficult satellites, although the elongation of I was occasionally suspected.

TABLE IV

SATELLITE II

1904		J. D. 2416	P. A.	Dev.	No.	Form	Eyes	Seeing
July	23	685.907	..	..	..	1.04	..	..
Aug.	6	699.924	..	..	..	1.04	..	..
	8	701.959	207.4	..	1	1.11	r	9
		.961	201.5	..	1	..	..	"
		.963	191.1	..	1	..	..	"
	9	702.044	200.3	4.2	4	1.11	r	"
		.060	192.7	5.8	4	1.10	"	"
		.913	181.9	2.4	4	1.11	"	8
	11	704.003	174.3	..	1	1.04	"	"
	12	705.990	196.2	2.6	4	1.11	"	"
	14	707.883	187.1	1.7	4	..	"	"
		.966	166.7	2.4	4	..	"	7
	15	708.003	157.8	3.8	4	1.10	"	8
		.910	147.1	7.4	4	1.06	"	"
	17	710.057	191.3	4.4	..	1.12	"	7
		.923	..	..	..	1.00	..	8
	18	711.035	190.4	2	2	1.06	r	7
	21	714.008	..	..	..	1.07	"	8
	22	715.947	..	..	..	1.08	"	"
	26	719.060	212.8	3.2	2	1.06	"	"
		.942	182.3	3.2	2	1.10	"	"
	27	720.961	190.8	3.2	1	1.08	..	7
Sept.	7	731.821	160.2	3.0	4	1.10	r	8
	9	733.795	158.4	4.6	4	1.09	"	"
	10	734.928	164.1	2.8	4	1.10	"	"
	12	736.832	167.9	3.2	4	1.09	"	7
	13	737.852	185.3	5.6	4	1.10	"	8

SATELLITE III

1904		J. D. 2416	P. A.	Dev.	No.	Form	Eyes	Seeing
July	23	685.903	171	..	1	1.10	r	7
	27	689.043	190.8	..	1	1.12	"	..
		.061	168	..	1	1.07	"	..
		.919	208	..	1	1.08	..	6
Aug.	1	694.036	180	..	1	1.13	..	5
	4	697.057	..	..	..	1.06	l	..
		.965	120	..	1	1.05	..	..
		.969	..	..	..	1.00	..	..
		.974	120	..	1	1.06	..	..
		.979	..	..	..	1.05	..	..
		.989	..	..	..	1.06	..	..
		.992	..	..	..	1.05	..	..
	5	698.002	..	..	..	1.05	..	..
		.032	135	..	1	1.05	..	..
		.039	..	..	..	1.07	..	..

SATELLITE III

1904		J. D. 2416	P. A.	Dev.	No.	Form	Eyes	Seeing
Aug.	5	698.045	..	..	..	1.05	..	..
		.047	148.5	..	1	..	..	..
		.049	156.5	..	1	..	..	..
		.055	143	..	1	..	..	..
		.056	157	..	1	..	..	..
		.062	..	..	..	1.06	..	..
		.915	..	..	..	1.09	..	..
		.923	..	..	..	1.09	..	..
		.939	124.4	..	1	..	..	..
		.941	..	..	..	..	..	8
		.948	145.2	..	1	..	..	..
		.950	..	..	..	1.09	..	..
		.952	123.8	..	1	..	..	..
		.972	..	..	..	..	..	8
		.974	149.9	..	1	1.09	r	7
		.985	153.9	..	1	1.09	l	"
	6	699.001	145.8	..	1	1.09	"	"
		.025	158.3	..	1	1.09	r	6
		.052	170.4	..	1	1.09	"	8
		.063	174.0	..	1	1.09	l	"
		.066	167.8	..	1	1.10	"	7
		.896	167.8	..	1	1.15	r	"
		.905	168.9	..	1	1.14	"	"
		.928	171.0	..	1	1.16	"	6
	7	700.897	148.5	..	..	1.09	"	"
	8	701.957	217	..	..	1.10	"	9
		.984	190.4	..	..	1.10	"	"
	9	702.007	202.5	2.7	4	1.10	"	"
		.074	197.2	4.6	4	1.08	"	"
		.896	160.9	9.4	4	1.05	"	8
	10	703.037	212.0	7.5	4	1.06	"	7
		.048	192.6	6.5	4	1.07	"	8
		.878	200.7	8.2	4	1.07	l	6
		.892	223.0	5.4	4	1.05	r	5
	11	704.011	185.9	5.4	4	1.08	"	8
		.958	156.2	16.4	5	1.06	"	7
	12	705.909	168.8	6.1	4	1.08	"	8
		.983	190.4	4	4	1.09	"	"
	14	707.910	160.4	7	4	1.11	"	"
	15	708.012	187.1	7	4	1.10	"	"
		.927	184.0	9.5	4	1.09	"	"
		.966	183.7	2.7	4	1.08	"	"
	16	709.902	198.6	3.4	4	1.11	"	7
		.915	206.2	6.7	4	1.07	l	"
	17	710.026	204.8	7.1	4	1.10	r	6
		.939	166.0	..	1	1.06	"	8

SATELLITE III

1904	J. D. 2416	P. A.	Dev.	No.	Form	Eyes	Seeing
Aug. 17	710.986	197.1	5.5	4	1.07	r	8
18	711.027	185.5	6.4	4	1.07	"	"
19	712.982	162.5	4.0	4	1.08	"	7
20	713.997	121.6	..	1	1.14	"	8
21	714.004	..	..	..	1.14	"	7
	.006	..	..	..	1.12	"	8
	.007	..	..	..	1.09	l	"
22	715.936	122.9	..	1	1.08	r	9
	.949	..	..	..	1.08	"	..
25	718.061	211.2	6.1	4	1.08	"	8
	.055	223.6	4.8	4	1.04	"	9
26	719.929	180.2	4.9	4	1.07	"	8
27	720.957	172.6	2.4	4	1.12	"	7
28	721.008	182.0	6.3	4	1.09	"	"
29	722.955	191.9	5.2	4	1.08	"	"
30	723.883	205.8	3.6	4	1.11	"	"
Sept. 1	725.014	187.3	7.2	4	1.05	"	"
3	727.892	167.9	5.8	4	1.09	"	"
6	730.875	228.2	6.9	4	1.06	l	6
7	731.793	195.1	2.5	4	1.06	r	8
8	732.793	113.1	11.0	4	1.04	"	"
9	733.785	12.58	8.0	4	1.05	"	"
10	734.892	165.2	1.7	..	1.08	"	"
12	736.750	..	..	..	1.00	..	6
	.773	..	..	..	..	..	7
	.786	148.6	4.0	4	1.07	r	9
13	737.822	194.4	4.9	4	1.06	"	7
	.821	198.7	3.4	4	1.10	"	7

SATELLITE IV

1904	J. D. 2416	P. A.	Dev.	No.	Form	Eyes	Seeing
July 23	685.905	96	..	..	1.10	r	7
27	689.048	192	..	..	1.12	"	..

SATELLITE IV

1904	J. D. 2416	P. A.	Dev.	No.	Form	Eyes	Seeing
Aug. 4	697.982	150	..	..	1.08	..	..
5	698.958	160.5	..	..	..	..	..
	.959	..	..	..	1.10	r	..
6	699.006	181.3	..	..	1.11	"	8
	.050	179.9	..	..	1.12	"	7
	.901	173.6	..	..	1.07	"	"
	.936	164.4	..	..	1.09	"	"
7	700.903	187.0	..	..	1.09	"	8
8	701.996	197.5	..	..	1.08	"	9
9	702.023	99.3	8.1	4	1.09	"	8
	.050	197.9	6.2	4	1.10	"	9
	.884	165.9	5.1	4	1.06	"	8
10	703.996	179.5	3.2	4	1.09	"	"
14	707.976	161.5	8.0	4	1.10	"	"
15	708.028	170.4	4.8	4	1.10	"	"
	.941	174.3	5.1	4	1.08	"	"
17	710.006	177.7	3.4	4	1.12	"	7
18	711.019	175.1	3.6	4	1.12	"	8
19	712.917	168.0	3.7	4	1.11	"	7
21	714.000	165.0	..	..	1.14	"	8
25	718.940	212.1	6.1	4	1.09	"	9
26	719.045	203.4	5.5	4	1.08	"	8
	.937	193.3	5.2	4	1.09	"	"
27	720.966	187.2	3.9	4	1.09	"	7
30	723.897	161.6	7.1	4	1.09	"	"
Sept. 1	725.020	178.2	4.5	4	1.08	"	"
3	727.011	180.9	4.8	4	1.08	"	"
7	731.811	171.5	2.8	4	1.11	"	8
8	732.805	153.8	16.8	4	1.08	"	"
9	733.806	182.4	2.6	4	1.11	"	"
10	734.920	195.2	2.7	4	1.08	"	"
12	736.801	142.9	..	1	1.09	"	"
13	737.845	174.8	1.1	4	1.08	"	"

MANDEVILLE, JAMAICA
June, 1923