ASTRONOMISCHE NACHRICHTEN.

N^o 3453.

Band 144.

21.

On the Third and Fourth Satellites of Jupiter.

By *E. E. Barnard.*

[With a plate].

I have been very much interested in Mr. Douglass' paper on the third and fourth satellites of Jupiter in A. N. No. 3432. During the latter part of my stay at the Lick Observatory, I also made a careful study of these two moons with the 36 inch equatorial. Though my observations by no means negative the values given by Mr. Douglass for their rotation periods, they do bear directly upon the surface features of the satellites.

According to Mr. Douglass' drawings and statements, he finds these satellites covered by a series of fine dark lines »the maximum width being estimated at less than 0".1 or 200 miles«. In appearance, from the drawings, these markings very much resemble those observed at the same observatory upon Mars, Venus and Mercury.

In my remarks, I shall assume that these narrow dark lines have existed all along on these moons and have simply escaped discovery until now. They will therefore have been equally visible during my observations in 1893-94-95.

As I failed to see these markings but saw others not shown by Mr. Douglass, it becomes a question of telescope and atmospheric conditions as to why he should see one thing and I should see another so wholly different in appearance.

I believe it to be a fact that no telescope existing — unless of course it is the Yerkes 40 inch when it is in working order — is so capable of showing the surface features of these satellites as the Lick 36 inch. I also believe there are brief intervals of good seeing at the Lick Observatory which are not excelled if indeed they are equalled at any other observatory.

For definite objects as small as the discs of the satellites of Jupiter, it must be admitted that such a telescope under such conditions must be extremely favorable for seeing any details that may exist on their surfaces, and that the chance of such a telescope showing them if they can be seen at all is very great — certainly far greater than those of any smaller telescope. Though I have observed and drawn markings on these satellites, I have not seen any narrow straight lines or similar markings on any of them.

The markings I have seen have always appeared to be large and more or less diffused — except in the case of certain white polar spots which will be specially treated of later.

Still it is possibly the old case of when a thing has once been pointed out by some one, it is easy enough for

any one else to see it with a proper instrument, so that after all, the markings drawn by Mr. Douglass may be easily visible now with the 36 inch. I shall hope to look for them with the 40 inch when the opportunity occurs.

Perhaps a word here in reference to planetary drawings in general, may not be out of place. It has always appeared to me that when representing any planetary detail it should be drawn as nearly accurate, as to appearance, as possible. If the marking is vague and uncertain it should be made so on the drawing and no definite outlines should be given where none exist. Some observers seem to be in the habit of giving a definite boundary to markings whether such are really seen or not. This is very misleading and no object should be shown with a definite outline unless it really has such.

This diagram method of drawing is specially noticeable in a good many drawings of Mars, and it is perhaps through the study of these and not by any inspection of the planet itself that so many queer and unnatural ideas have been propagated concerning the physical appearance of Mars. Many of the regions shown on drawings and maps of Mars as definitely bounded, are in reality very diffused and uncertain in their outlines.

The markings that I have seen on the satellites of Jupiter are of this vague and uncertain nature — that is, though they were conspicuous enough, they were so vague in form that at no two times was it possible to say definitely that the same marking was under observation. In the drawings herewith given, I have tried to show these markings as nearly correct as possible and they are therefore necessarily very vague in form.

The bright polar caps I have mentioned, however, are usually very conspicuous and well defined — especially at their inner borders. In appearance they are exactly like the polar caps of Mars. In the case of the third satellite, the cap is situated at the north limb and has been seen so bright as to apparently stick out from the satellite. On two occasions I have recorded the satellite as having a white south polar cap, though the two caps were not seen at the same time. The white cap on III was first seen by me Oct. 8, 1891, with the 36 inch when observing Jupiter with Mr. Burnham.

The polar cap of the fourth satellite, which is nearly as distinct as that of III, is situated at the south limb of IV, though on one occasion a white cap was seen at its

north limb — at the same time the north polar cap of III was conspicuously visible.

The north polar cap of the third satellite has sometimes been very large, especially on Nov. 18, 1894, when it was about $\frac{1}{4}$ to $\frac{1}{3}$ the diameter of the satellite.

On a number of occasions the position angles of these caps were measured with reference to the center of the satellite. This was rather difficult, but I believe the results can be depended on to two or three degrees.

To show what effect the position of the satellite in its orbit had upon the visibility of the polar caps, I have roughly drawn the enclosed diagram, showing the orbital position of the third satellite at the times of observation. These are only approximately correct as they refer to the line of geocentric conjunction at the time of observation, and this has been assumed constant during the observations, and is sufficiently accurate for the purpose in view, as the greatest deviation from the mean position will only be 3° or 4° on each side of the adopted line of conjunction.

For the means of ready inspection, I have marked those positions of the satellite when the north polar cap was visible, with a +, and those when it was not visible with a --.

It will at once be seen that these separate themselves into two groups, from which it will also be seen that during these observations, the white spot was always visible on the following side of the planet and was never seen by me on the preceding side. Had the spot not been seen on the fifth of February 1895, I should have been tempted to think it had disappeared from the satellite at the close of 1894. It will be noticed that the observations of 1894 were essentially all made with the satellite following and those of 1895 with it preceding. This was because the observations were separated by one week, which is closely the period of the satellite. This always placed the satellite in the same part of its orbit at the observations for a long period of time.

If the observations of 1893 are similarly plotted, it will be seen that when the spot was reported visible, the satellite was also on the following side of Jupiter. In that year the visibility of the spot alone was recorded but in 1894-5 a close record was also kept of its invisibility.

If these are true polar caps we see on these moons — and I think they are — it is strange they should be hidden during part of their revolution about the planet. Unless they are excentrically placed with reference to the poles of rotation, they could only be hidden by the gradual revolution of Jupiter about the sun.

The drawings.

The drawings for 1893 Sept. 17 and Nov. 6 show what seems to be a rather wide diffused belt on the third satellite, with a large diffused spot extending southwards from the belt; in the first of these drawings the spot is towards the south following limb of the satellite, while in

that for Nov. 6 a similar spot — was it the same? — is shown extending towards the south preceding edge.

The position angle of this belt was carefully measured at the two observations

1893 Sept. 17 $13^h 40^m$ P.A. = 108.3 (4 obs.)

1893 Nov. 6 11.45 P.A. = 111.3 (2 obs.)

The observed position angles of the belts of Jupiter on these dates were :

1893 Sept. 17 P.A. = 78.0 (1)

1893 Nov. 6 P.A. = 77.4 (5)

It would therefore appear that the belt on the satellite was inclined at these observations to the equator of Jupiter by the following amounts :

Inclination satellite belt to equator
of Jupiter

Sept. 17 30.3 , Nov. 6 33.9 .

If the dusky spot is the same in each case, then these two drawings would negative a rotation period coincident with that of the revolution of III about Jupiter.

The two drawings of 1893 Sept. 24 and 1893 Nov. 6 (the second one for this date) show the effect of surface markings on the appearance of this satellite in transit. The dark spots being about the albedo of the planet are lost for want of contrast with the surface of Jupiter, giving thus a deformed appearance to the satellite. These four drawings were reproduced in *Astronomy and Astrophysics* No. 124.

A few discrepancies occurred in the reproduction then and the present drawings, carefully made from the originals, are to be accepted in their place.

In the drawing of 1894 Oct. 21 the north following limb of the third satellite was deficient as if effected with phase.

In many of the drawings — those showing the north polar cap of III — there was persistently present a very dark diffused spot south following the polar cap and close to it.

The transit of III on Sept. 3, 1894, was very remarkable. The satellite appeared as a black or very dark spot; on its disc and close to the south limb of the satellite, was a small round very white spot — fully as conspicuous as I have shown it. No other details however were seen on it.

Following are the times corresponding to the drawings.

They, as well as all the other times mentioned in this paper, are in Pacific Standard time, which is 8^h 0^m 0^s slow of Greenwich.

Times of the Drawings.

1893 Sept. 17	13 ^h 40 ^m	1894 Oct. 7	17 ^h 35 ^m
» 24	16 58	» 21	14 20
Nov. 6	11 54 I	» 28	14 0
» 6	13 35 II	» 29	14 20
Dec. 3	13 30	Nov. 5	14 50
» 11	9 18	» 11	13 35
» 11	9 20	» 12	13 10
1894 Sept. 3	17 34	1895 Mar. 29	7 10
» 16	16 41	1893 Dec. 10	12 5
Oct. 7	17 30	» 10	12 0

These last two drawings were overlooked in arranging the others, and are inserted to show the appearance of the polar caps. These two drawings showed no detail on the surface of the satellites.

The white north polar cap on Satellite III.

Date	Pac. St. T.	Visibility and P. A.	Remarks	Date	Pac. St. T.	Visibility and P. A.	Remarks
1893				1894			
Dec. 3	13 ^h 30 ^m	yes	Dark area following	Dec. 30	15 ^h 0 ^m	no	
10	9 25	yes		1895			
11	12 5	yes		Jan. 6	8 20	no	Image not very clear
1894				6	10 0	no	
Sept. 16	16 41	yes	Dark region n. f. middle	Febr. 4	8 25	no	» Seeing good enough for it«
Oct. 7	17 26	359.8 (4)		5	6 50	yes	» Very noticeable«
21	14 15	8.3 (4)	Very noticeable	18	10 0	no	Disc of satellite clear at times
28	14 0	yes	Very striking	24	11 20	no	
29	14 20	1.7 (5)	Very consp., dark region n. f.	25	10 45	no	
Nov. 4	13 55	12.6 (5)	Very consp., dark region n. f.	Mar. 3	9 0	no	» Ought to be easily seen«
5	14 50	6.8 (4)	Very striking, dark region n. f.	4	7 0	no	Disc well seen
12	13 5	356.3 (4)	Dark region n. f.	10	9 0	no	Ought to be seen, f. half darker
18	14 0	13.9 (4)	1/4 to 1/3 diameter of satellite	24	9 1	no	
19	13 30	181.2	» On south limb of III«	31	7 5	no	A definite observation
Dec. 23	12 40	no	Satellite near occultation	April 15	7 0	no	
30	14 0	no					

Notes on the third satellite.

1893.

Oct. 1 13^h 30^m. There seems to be a dark belt on III.

Dec. 3 13^h 30^m. The satellite has a light north polar cap. A dark region following the center of the satellite.

Dec. 10 9^h–12^h. The north pole of the satellite is white.

1894.

Sept. 16 16^h 41^m. There is a dark region north following the middle of the satellite and quite a white spot at the north limb.

Oct. 21. The white spot at the north limb was easily seen and very noticeable.

Oct. 28. The white spot is very conspicuous. It almost stands out from the satellite, it is so bright. The satellite is light at the south limb but there is no definite spot.

Oct. 29. The north polar cap is very conspicuous, a sketch shows on north following part of the satellite a dark region.

Nov. 4 15^h 0^m. The north polar cap is very prominent. It seems to be bordered by a dark band. The north following half of the satellite is darkest.

Nov. 5. In moments of good definition the white polar cap is very striking. This spot or cap always seems to be well defined especially at its south border. The polar cap seems almost to stick out from the satellite. There is a blackish diffused area close south following the edge of the polar cap.

Nov. 12. In all my observations of III for the white spot it appears just the same. The disc seems to have an indefinite dark marking on it close south following the cap.

Nov. 18. The polar spot is as before. It is 1/3 to 1/4 the diameter of the satellite.

Dec. 30 14^h 0^m can not see the white polar cap. Same 15^h 0^m.

1895.

Jan. 6. White spot not seen. The image of the satellite is not very clear. 10^h 0^m can not see any marking on III.

Febr. 4. This satellite is approaching occultation. Can see no trace of the white spot at its north limb. Once in

a while the seeing is good enough to show it if it were there. $12^h 30^m$ occasionally the image is very good. Vague dark markings are visible on the satellite but no white spot at north limb. Thought several times that there was a very thin narrow white place at north limb, but not sure. Certainly the white spot can be no ways as conspicuous as formerly or it would be seen easily.

Febr. 5 $6^h 50^m$. The white spot at north limb of III is very noticeable with 520. Seeing 3 to 4. It could not have been missed last night. I was unable to get measures as the seeing got bad and the spot could not be seen again.

Febr. 18 $10^h 0^m$. The disc of the satellite clearly seen at intervals; no white spot.

Febr. 24 $11^h 20^m$. For upwards of an hour have tried to make something out of III. During momentary glimpses of good seeing the disc could be seen fairly well, but no white spot was visible. Perhaps it should not have been seen on account of bad seeing.

Febr. 25 $10^h 45^m$. Carefully watched the satellite; for moments the air would be steady and the disc fairly seen but could see nothing of the white spot. In general the seeing, however, was too indifferent to warrant its being seen.

March 3 $9^h 0^m$. Can see nothing of the white spot. The central part of the satellite appears a little dusky across the disc towards Jupiter. The white spot ought to be easily seen if as at previous observations.

March 4. The disc well seen but the white spot invisible, good seeing. Satellites II and III are almost exactly the same brightness surface for surface.

March 10 $9^h 0^m$. There is a great deal of stray light but the disc of the satellite clearly seen. The white spot cannot be seen. The satellite is dark in the middle — a darkish smear across it towards Jupiter, the polar regions are both a little brighter than the rest of the disc but no definite white spot. It ought to be seen if on the disc, as the seeing is good. The following half of the satellite is darker.

March 24 $9^h 0^m$. The satellite's disc is fairly well seen at times but no white spot at either pole. It is darker across the middle towards Jupiter.

March 31. There is no white spot at the north limb. This is certain and definite. The following half of the satellite is dusky — a large dusky area. Occasionally for a few seconds the seeing is 5. The disc of III clear cut. There is no white spot, certain.

April 15 $7^h 0^m$. The following half of the satellite has a large dark region on it. There is no white cap.

At mid transit on Sept. 24, 1893 the south limb of the satellite exactly coincided with the south limb of Jupiter.

1894 Sept. 3. The following measures were made with the 36 in. micrometer of the position of the center of III while in transit on this date:

$17^h 29^m$ from north limb of Jupiter $29^{\circ} 07' (2)$

$17^h 31^m$ from south limb of Jupiter $12^{\circ} 70' (2)$

(These measures are perpendicular to the belts of Jupiter).

By careful estimation with micrometer wire, the satellite was in mid transit at $17^h 43^m 41^s$.

I have assumed that during Mr. Douglass' observations of the third satellite, the white polar cap was not visible,

as he shows nothing of it in his drawings. It was however seen by him, and by Prof. W. H. Pickering in 1893. See *Astronomy and Astrophysics* for June 1893.

The white south polar cap on Satellite IV.

Date	Pac. St. T.	Visibility and P. A.	Remarks
1893			
Dec. 10	$12^h 5^m$	yes	
1894			
Sept. 16	$16 52$	no	
Oct. 7	$17 35$	$170^{\circ} 1 (4)$	
21	$14 15$	no	
28	$13 55$	110°	North. Very striking
29	$14 20$	no	
Nov. 4	$13 55$	no	
5	$15 5$	no	
11	$13 35$	no?	A very small whitening
15	$15 0$	possibly	
1895			
Mar. 3	$9 0$	no	
4	$7 0$	no	
31	$7 5$	no	

Notes on Satellite IV.

1894.

Oct. 29. There is no cap at either pole of IV. It is a little darker in the middle.

Nov. 5 $15^h 5^m$. There is no white spot on IV — the surface is free from markings of any kind.

Nov. 11 $13^h 35^m$. There is a light place at the south limb of IV, but not a distinct cap.

Nov. 19. A white spot thought to be seen at the south limb of IV.

1895.

March 3 $9^h 0^m$. This satellite is dusky. Nothing seen upon it.

March 4 $7^h 0^m$. No markings are seen on the satellite. Its equatorial region appears possibly a little brighter.

I shall not here enter into any discussion as to the reported ellipticities and malformations of the discs of the satellites of Jupiter when seen on the dark sky.

I have shown (*Astronomy and Astrophysics* No. 124) that there are apparent deformations of these bodies during their transits from dark markings upon their surfaces. But that the actual outline of a satellite is so conspicuously elliptical as has been drawn and described by some observers, passes my understanding entirely, for I have observed these bodies under the best conditions and with the most powerful telescopic means, with the special intent of verifying these reports (see *Astr. and Astroph.* 124), but the satellites have always appeared round to me when seen free from the planet. I have also tried under the best conditions and with all sorts of telescopes to see one of these bodies through the limb of Jupiter at occultation, but have never seen a trace of the alledged transparency of the limb of the planet either where a dark belt or a white one touched the limb.

South

III

1893 Sept. 17

III

1893 Sept. 24

III

1893 Nov. 6 I

III

1893 Nov. 6 II

III

1893 Dec. 3

III

1893 Dec. 11

IV

1893 Dec. 11

III

1894 Sept. 3

III

1894 Sept. 16

III

1894 Oct. 7

IV

1894 Oct. 7

III

1894 Oct. 21

III

1894 Oct. 28

III

1894 Oct. 29

III

1894 Nov. 5

IV

1894 Nov. 11

III

1894 Nov. 12

III

1895 March 29

IV

1893 Dec. 10

III

1893 Dec. 10

For observations bearing on this subject see *Astronomy and Astrophysics* No. 124.

I have also shown that the peculiar features of a double dark spot and an elongated white spot, shown by the first satellite in transit (attention to which was first called by me at the transit of Sept. 8, 1890, see A. N. 2995, M. N. vol. LI p. 547, vol. LV p. 388, vol. LIV p. 134 etc.), are all due to the fact that this satellite has very dark poles and a bright equatorial region. These features cause the satellite, when it transits a bright part of Jupiter, to appear double — as two small dark spots in a line nearly perpendicular to the belts of Jupiter — the dark polar caps alone being visible against Jupiter. When it crosses a dark part of the planet, the bright equatorial regions, ordinarily, are alone visible, and the satellite appears as a very elongated bright spot nearly parallel to the belts of Jupiter. I have also shown that these same features might cause the satellite to appear more or less elongated when off the planet.

There is absolutely no question as to the correctness of this explanation, for I have, on a number of occasions, seen this satellite in transit clearly relieved as a beautiful round globe with very dark poles and a bright equatorial region. I have plenty of the most convincing proof of this peculiarity of the first satellite of Jupiter, if further proof should be wanting. This matter I consider settled for all time.

As I have said, I have often watched Satellite I in transit with the 36 inch and have thoroughly verified the existence of its dark polar caps and bright equatorial region.

With a powerful telescope these peculiarities produce very beautiful phenomena during transit. One of these I have shown in a drawing in M. N. LIV p. 134 where the satellite was seen in beautiful relief partly occulting its own shadow on 1893 Nov. 19. On that occasion the dark polar caps were very beautifully shown.

I have two other drawings (among many others) that show most elegantly the phenomena produced at transit by the dark polar caps. These drawings which I give here were made with the 36 in. 1894 Oct. 14 when the satellite transited the region of the great Red Spot Bay. The first drawing shows the satellite very elongated. Its polar regions were just as dark as the great belt that forms Red Spot Bay and nothing of the satellite was visible but its bright

1894 Oct. 14. Transit of Sat. I over Red Spot Bay.

17^h 45^m

18^h 10^m

equatorial regions. A half hour later it had moved along into the lower part of the bay and a portion of its southern half was projected off the belt on to the bright surface of Jupiter, thus bringing boldly into relief the dark southern hemisphere and bright equator of the satellite. At this time the satellite presented a very striking picture just under the great red spot.

In all the observations of these satellites a power of 1000 was used, though higher and lower powers were often tried. One thousand, however, showed them best with the 36 inch.

In conclusion let me say that I have a great many observations of the four satellites of Jupiter — eclipses, transits, etc., also a great many transits of spots on the surface of Jupiter, including many of the great red spot, which have yet to be published.

I would also say that several times, in watching the eclipses of the satellites of Jupiter with the 36 in., I have carefully searched for the satellite in the shadow of the planet, but no trace could be seen of it. An eclipse of one of these moons seen with the great telescope is a very beautiful phenomenon as every phase of the eclipse down to the narrowest crescent is conspicuously shown.

In reference to the drawings of the polar caps of the satellites I would say that they are not oriented exact enough for measurement of their position angles etc.

At the next opposition of Jupiter I hope to take up the study of these moons under very favorable conditions.

Yerkes Observatory, Williams Bay, Wisconsin U. S. A., 1897 August.

E. E. Barnard.

Postscript.

Correction to Proctor's »Old and New Astronomy«.

I hope that I may be permitted, in connection with my subject, to call attention to an error that has occurred in Proctor's »Old and New Astronomy«.

On p. 576 are given several drawings of the planet Jupiter, showing the great red spot. Under figure 391 is the inscription »Great oval red spot on Jupiter in 1877« and on p. 575, referring to this drawing, one is lead to believe that it was probably made by Professor Pritchett of Glas-

gow, Missouri, in 1877. This drawing was really made by me on the morning of Aug. 18, 1880 at 4^h 19^m Nashville (Tennessee) mean time. It is one of two that were printed in the *Scientific American* either in the latter part of 1880 or the first of 1881. I have the original drawing yet, which was returned to me by the Editor of the *Scientific American* after he had used it for his illustration.

E. E. B.