NEW MEXICO STATE UNIVERSITY
LAS CRUCES, NEW MEXICO 88001
AREA 505 646-2614

Observatory

LATITUDE AND LONGITUDE MEASUREMENTS OF JOVIAN FEATURES IN 1967-68

E. J. Reese

and

H. G. Solberg

The Observatory*
New Mexico State University
Las Cruces, New Mexico 88001

April 1969

*TN-701-69-28
Supported in part by NASA Grants NGL 32-003-001 and
NGR 32-003-027

LATITUDE AND LONGITUDE MEASUREMENTS OF JOVIAN FEATURES IN 1967-68

E. J. Reese and H. G. Solberg

ABSTRACT

Photographic observations of Jupiter during the apparition of 1967-1968 *are discussed. Several interesting oscillations and accelerations in the motions of atmospheric features are described in detail. Photographic measurements of the latitudes of the Jovian belts and a number of selected features are summarized.*

INTRODUCTION

For several years the New Mexico State University Observatory has been engaged in a photographic patrol of the planet Jupiter. The patrol is designed to give a photographic record of every longitude of the planet in blue, green, and red light at least once every six days. Photographs in infrared and ultraviolet light are taken at less frequent intervals. Observations are just as numerous when the planet is in the morning sky as in the evening sky, and every effort is made to minimize the interval during which Jupiter is not observed because of proximity to the sun. Each photographic plate has a sensitometric step wedge for photometric work, and a fiducial line for orientation purposes. The Universal Time for each image is recorded to the nearest second by a digital recorder.

This photographic record provides an excellent basis for systematic work in following the motions of Jovian spots in longitude and latitude. We have been making a large number of measurements of selected Jovian spots with a Mann measuring machine using techniques described elsewhere (Reese and Solberg, 1966). We have found some interesting oscillations in the motions of spots which probably would have been missed in the past because of insufficiently accurate data.

A number of interesting events took place on Jupiter during the apparition of 1967-68. The Equatorial Band attained a width and darkness--especially in blue light--that has never before been equalled, not even in 1938 (Peek, 1958, p. 97). A small yellow spot in the South Polar Region at zenographic latitude -60° had a mean rotation period of $9^h55^m12^s$ which is unique in the records of the planet for that latitude. A very dark streak which developed in the middle of the South Temperate

Belt greatly resembled the "Red Streak of 1891" (Reese, 1968). The highlight of the appraition, however, was the appearance of a small dark spot on the south edge of the North North Temperate Belt which, by its rapid rotation, proved to belong to the rarely observed N. N. Temperate Current B which was last observed in 1945. This NNTBs spot was all the more interesting since its motion in longitude displayed a nearly perfect free oscillation having an amplitude of 3°.4 in longitude and a period of 66.4 days.

The terminology and abbreviations used in this report are similar to those used by Peek (1958). In addition, we sometimes use $^{n}/$ and $^{s}/$ to denote the north and south edges of an object.

LATITUDE MEASUREMENTS

A total of 632 measurements were made of the latitudes of the Jovian belts and 18 selected features during 1967-68. Most of the plates measured were taken in blue light since the limb of the planet is best defined in this color. However, certain features, such as the Red Spot Hollow and the small yellow spot in the South Polar Region, were measured on plates taken in red light since they did not show up well on plates taken in blue light. Table I, which summarizes the belt latitudes, divides the apparition into three parts so that any progressive changes in latitude might become apparent. A poleward trend of the north edge of the South Temperate Belt and an equatorward trend of the south edge of the SEBn are probably real. Other apparent trends are not appreciably larger than the standard deviation of the measurements. Generally, the belts on Jupiter are remarkably fixed in latitude. The latitude of a belt may vary with time and longitude, but only within rather small limits.

For the most part the belts were near their normal latitudes in 1967-68 (Solberg and Reese, 1969). The Equatorial Band was unusually dark and wide, and the poleward edges of the North Equatorial Belt and the South Equatorial Belt were a little further from the equator than usual. The South Polar Belt near latitude -67° was quite dark and well-defined despite its location in the dusky polar region. The dark belt in the middle of the South Tropical Zone at latitude -24°.4 is an unusual feature which appeared to emanate from the preceding tip of the Red Spot and to fade away about 90° preceding the Red Spot. This belt may have been an aftermath of the violent interaction of SEBs spots with the Red Spot during the two preceding apparitions.

Latitude measurements of selected spots will be summarized in the following sections which deal with the longitudes and rotation periods of those spots.

ROTATION PERIODS OF INDIVIDUAL SPOTS

We will now summarize reductions made from measurements of the longitudes of individual spots.

<u>Small Yellow Spot in the South Polar Region</u>

Mean zenographic latitude, β'' = -59°.9 ±0°.4 (7 dates).

Mean width in latitude = 3°.7 ±0°.3 (7 dates).

Mean length in longitude = 5°.2 ±0°.2 (12 dates).

Object	1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
Yellow Spot	Jan 16--Mar 15	229°.7--187°.1	12	-0°.7222	$9^h55^m11^s.0$	$\pm1^s.5$

The drift of this spot in longitude was definitely nonlinear (Fig. 1). At least squares polynomial solution indicates that the spot was subjected to constant acceleration in its rate of drift in decreasing System II longitude. The computed longitude at any time, T, expressed in days from 1 September 1967, is given by the equation:

$$\lambda_2 = 140\overset{\circ}{.}5 + 1\overset{\circ}{.}612T - 0\overset{\circ}{.}007T^2$$

From this it follows that the daily drift of the spot in System II longitude at any time, T, was 1°.612 -0°.014T. Thus, when first observed on 16 January, the spot had a rotation period of $9^h55^m28^s$ which is normal for its latitude; but when last observed on 15 March, the period had decreased to the unusual value of $9^h54^m54^s$.

During the interval of observation, the spot moved slowly but steadily poleward in latitude. A linear least squares solution of the latitude measurements placed the center of the spot at -58°.6 ±0°.2 on 16 January and -61°.1 ±0°.3 on 15 March, a shift of 2½ degrees in two months.

If this small, yellow spot had behaved as a closed system conserving angular momentum, its rotation period would have decreased to $8^h34^m38^s$ after it had moved 2°.5 poleward. The fact that its period decreased only to $9^h54^m54^s$ might indicate that the spot lost rotational velocity as it moved poleward due to resistance from more slowly moving atmospheric currents in higher latitudes.[1] Peek (1958) has suggested that the South Polar Region from latitude -45° to the pole might have a fairly uniform rotation period of about $9^h55^m30^s$. Such an atmosphere would have a rotational velocity at latitude -61°.1 which would be only 0.9296 as great as at latitude -58°.6. The observed velocity[2] of the spot at latitude -61°.1 was 0.9304 of its velocity at latitude -58°.6. The rotational velocity of the spot actually underwent a deceleration of 0.94 x 10^{-4} m/sec^2 rather than accelerating 1.02 x 10^{-4} m/sec^2 as would a closed system. However, relative to a meridian rotating at the uniform rate of System II, the spot actually accelerated 0.01 x 10^{-4} m/sec^2 rather than accelerating 1.97 x 10^{-4} m/sec^2 as would a closed system. Hence the spot appeared to behave as a system conserving angular momentum, but with loses due to resistance corresponding to a deceleration of 1.96 x 10^{-4} m/sec^2.

Small White Spot in SSTeZ (S.S.S. Temperate Current)

Mean zenographic latitude, β" = -50°3 ±0°2 (5 dates)

Mean width in latitude = 4°3 ±0°4 (5 dates)

Mean length in longitude = 5°8 ±0°3 (8 dates)

Object	1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
White Spot	Jan 16--Feb 27	218°7--218°1	8	-0°0148	$9^h55^m40^s.0$	$\pm 1^s.5$

Spots in Southern Part of STeZ (S.S. Temperate Current)

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
1 (Wf)	Sep 18--Jan 22	201°5--90°0	10	-0°8851	$9^h55^m4^s.3$	$\pm 0^s.6$
2 (Wf)	Oct 3--Jan 31	298.8--192.1	5	-0.8891	9 55 4.2	±0.6
3 (Wc)	Dec 7--Apr 6	283.4--174.9	12	-0.8973	9 55 3.8	±1.0
4 (Wc)	Dec 7--Jun 7	291.5--125.9	15	-0.9050	9 55 3.5	±0.2
5 (Dc)	May 11--Jun 30	30.8--346.9	8	-0.8784	9 55 4.6	±1.8

Mean rotation period - $9^h55^m4^s.0$

Object	Mean Latitude	Mean Width	Mean Length
3 (Wc)	-40°9 ±0°1 (5 dates)	3°5 ±0.1 (5 dates)	4°0 (13 dates)
4 (Wc)	-39.1 ±0.2 (2)	5.4 ±0.7 (2)	8.0 (15)
5 (Dc)	-39.2 ±0.4 (3)	4.7 ±0.7 (3)	10.5 (9)

The two white spots, numbers 3 and 4, remained in close proximity to each other at all times, although they were closer together at the beginning and end of the observing interval than they were near the middle of that interval. Spot 3, which was a little south of the other spot, underwent a small but constant deceleration throughout its observed life, while the drift of Spot 4 was very nearly linear. A least squares solution gives the following equation for the motion of Spot 3:

$$\lambda_2 = 410^{\circ}\!.4 - 1^{\circ}\!.4922T + 0^{\circ}\!.0019T^2$$

where T is the time expressed in days from 1 September 1967. The daily drift in System II at any time, T, is equal to $-1^{\circ}\!.4922 + 0^{\circ}\!.0038T$. Thus the rotation period varied from $9^h54^m54^s\!.6$ to $9^h55^m13^s\!.4$.

<u>The Long-Enduring South Temperate Ovals (S. Temperate Current)</u>

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
FA	Nov 1--Jul 18	343°3--178°3	29	-0°6349	$9^h55^m14^s\!.6$	$\pm0^s\!.1$
BC (early)	Sep 29--Feb 2	108.0-- 31.5	17	-0.6072	9 55 15.7	±0.2
BC (late)	Feb 2--Jul 21	31.5--276.0	22	-0.6790	9 55 12.8	±0.2
DE (early)	Sep 16--Apr 19	250.1--109.6	27	-0.6506	9 55 13.9	±0.2
DE (late)	Apr 19--Jul 22	109.6-- 42.6	14	-0.7116	9 55 11.4	±0.5

Mean rotation period of BC = $9^h55^m14^s\!.0$

Mean roration period of DE = $9^h55^m13^s\!.2$

Mean rotation period of all = $9^h55^m13^s\!.9$

Object	Mean Latitude	Mean Width	Mean Length	Longitude II at opposition
FA	-33°.3 ±0°.1 (6)*	6°.0 ±0°.5 (6)*	12°.7 ±0°.4 (37)*	272°.9
BC	-32.9 ±0.1 (12)	7.2 ±0.3 (12)	13.8 ±0.3 (47)	19.2
DE	-33.4 ±0.1 (8)	6.7 ±0.3 (8)	13.9 ±0.3 (42)	147.8
Mean	-33°.2	6°.6	13°.5	

*NOTE: Number of dates on which observations were made are given in parenthesis.

The drift of BC in longitude appeared to be composed of two essentially linear sections with a sharply defined bend at the point of intercept caused by a sudden acceleration near 2 February 1968 when the bright oval was nearing conjunction with the Red Spot. Conjunction occurred on 9 February at longitude (II) 27°.0. DE, on the other hand, accelerated rather suddenly near the end of March when it was about 80° following the Red Spot. The subtle, but persistent, influence of the Red Spot region on the rotational velocity of the South Temperate Ovals (Reese, 1967) continues to be in evidence.

<u>White Spot in Middle of STB (S. Temperate Current)(β''=-30°)</u>

Mean length in longitude = 6°.0

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
White Spot	Oct 3--Jan 16	290°.4--227°.1	8	-0°.6027	$9^h55^m15^s.9$	±0°.4

This small, bright spot closely preceded the long, dark streak described in the next section. The drift of the bright spot was essentially linear.

Dark Streak in Middle of STB (S. Temperate Current)

Mean zenographic latitude = -30°.4 ±0°.1 (11 dates)

Mean width in latitude = 4°.1 ±0°.5 (11 dates)

Mean length in longitude = 17°.3 ±0°.3 (31 dates)

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
Dark Streak (early)	Oct 15--Jan 1	310°.4--254°.5	10	-0°.7137	$9^h55^m11^s.3$	±0°.3
Dark Streak (late)	Jan 1--Mar 10	254.5--212.9	21	-0.6038	9 55 15.9	±0.5

Mean rotation period of dark streak = $9^h55^m12^s.4$

A description of this conspicuous dark streak has already been published (Reese, 1968). The streak began to fade in early March and was last photographed on 15 March when its center was at longitude 205°.6 and its length had decreased to about 14°. As the streak faded, its motion in decreasing longitude accelerated. The rotation period from 8 to 15 March was $9^h54^m39^s$. There may be a tendency for dark spots to accelerate during intervals when they are fading rapidly. A few very small condensations were recorded in the STB near the extrapoloted longitude of the dark streak during the latter half of March and early April; however, these fragments bore no resemblence to the former streak.

Dark Spots on North Edge STB (S. Branch of Circulating Current)(β''=-26°.1)

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
1	Dec. 8--Feb 16	144°.0--308°.5	6	-2°.7939	$9^h53^m46^s.3$	±0^s.6
2	Feb 20--Mar 13	269.7--199.6	5	-3.1863	9 53 30.3	±1.1
3	Mar 13--Apr 20	329.3--222.4	7	-2.8131	9 53 45.5	±1.4

Mean rotation period = $9^h53^m40^s.7$

Spot 1 apparently moved past the south edge of the Red Spot on 20 January without being caught in the Red Spot vortex as was a similar spot in January, 1966 (Reese and Smith, 1968). The drift of Spot 1 seems to be reliable since all of the measured longitudes fall within 1° of a linear least squares line, and the drift closely parallels those of spots 2 and 3. The mean lengths of spots 1, 2, and 3 were $4\overset{\circ}{.}7$, $4\overset{\circ}{.}1$, and $5\overset{\circ}{.}0$ respectively.

Red Spot Hollow

Mean zenographic latitude = $-22\overset{\circ}{.}18 \pm 0\overset{\circ}{.}15$ (11 dates)

Mean width in latitude = $8\overset{\circ}{.}8 \pm 0\overset{\circ}{.}2$ (11 dates)

Mean length in longitude = $17\overset{\circ}{.}8 \pm 0\overset{\circ}{.}3$ (25 dates)

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
RSH	Oct 1--Mar 16	$27\overset{\circ}{.}2$--$26\overset{\circ}{.}8$	25	$-0\overset{\circ}{.}0028$	$9^h55^m40\overset{s}{.}5$	$\pm 0\overset{s}{.}1$

Longitude (II) at opposition = $26\overset{\circ}{.}8$

Measurements of the length and width of the Red Spot Hollow were for the bright interior of that object and did not include the dark border.

The drift of the Hollow (Fig. 2) was nonlinear and greatly resembled a damped harmonic oscillation of the form:

$$\lambda_2 = a + bt + ce^{-kt} \sin \theta t$$

A general least squares solution gives the following equation for the Hollow's motion in longitude with no residual being greater than $0\overset{\circ}{.}39$:

$$\lambda_2 = 27\overset{\circ}{.}03 - 0\overset{\circ}{.}0028t + 0\overset{\circ}{.}649\ e^{-0.014t} \sin 5\overset{\circ}{.}2941t$$

The period of oscillation was 68 days, and t is the time in days from 14 December 1967. It is of interest to note that the oscillating spot of 1940-41 had a nearly identical damping coefficient, k, of 0.015 (Peek, 1958).

Longitude measurements of the Hollow were carried out at a time when the Hollow was very bright and well defined in red light (Fig. 3) while the Red Spot was very faint and diffuse in blue light. As the Red Spot darkened late in the apparition, the Hollow became poorly defined and measurements of the Hollow were discontinued. Although the oscillations of the Red Spot and the Hollow generally were in phase with one another, the amplitude of the Red Spot's oscillation was much greater than that of the Hollow (Fig. 4).

Photographs taken in green light clearly show a variable displacement of the Red Spot towards the following end of the Hollow. Later in the apparition, the outline of the Red Spot expanded until it apparently coincided with what was formerly the dark border of the Hollow.

Red Spot

Mean zenographic latitude = $-23^{\circ}\!.0$ (59 dates)

Mean width in latitude = $10^{\circ}\!.0$ (59 dates)

Mean length in longitude = $19^{\circ}\!.8$ (90 dates)

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2/\text{day}$	Rotation Period	S.D.
RSc	Sep 12--Jul 17	$28^{\circ}\!.0$--$26^{\circ}\!.7$	90	$-0^{\circ}\!.0043$	$9^h55^m40^s\!.5$	$\pm0^s\!.1$

Longitude (II) at opposition, 20 February 1968 = $26^{\circ}\!.2$

During the apparition, the Red Spot increased greatly in size and became much more prominent. The behavior of the Red Spot during the apparition has been discussed (Solberg, 1969).

White Spot in Northern Part of South Tropical Zone (β''=-21°.8)

Object	1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period	S.D.
White Spot	Jan 22--Mar 6	325°.1--340°.6	10	+0°.3528	$9^h55^m55^s.1$	$\pm1^s.9$

The drift of this spot was quite sinuous, due perhaps to its nearness to the line of shear betweeen the South Tropical Current and the retrograde current on the south edge of the South Equatorial Belt. The spot was elongated in the direction of rotation and had a length of 5°.6 and a width of 2°.1.

Dark Spots on South Edge SEBs (N. Branch of Circulating Current)(β''=-21°)

Object	Limiting Dates 1967--1968	Limiting Longitudes	N	$\Delta\lambda_2$/day	Rotation Period
1	Sep 18--Nov 8	195°--338°	7	+2°.8039	$9^h57^m36^s.1$
2	Sep 29--Nov 20	76 --245	9	+3.2500	9 57 54.6
3	Nov 10--Dec 7	181 --268	3	+3.2222	9 57 53.5
4	Nov 9--Dec 7	151 --247	3	+3.4285	9 58 2.0
5	Nov 4--Jan 3	119 --328	6	+3.4833	9 58 4.2
6	Nov 4--Jan 5	100 --316	9	+3.4838	9 58 4.2
7	Dec 1--Jan 13	174 --329	7	+3.6046	9 58 9.2
8	Dec 23--Jan 29	235 --356	6	+3.2702	9 57 55.4
9	Nov 14--Jan 24	90 --329	8	+3.3661	9 57 59.4
10	Nov 14--Jan 5	66 --231	7	+3.1730	9 57 51.4
11	Jan 16--Feb 11	257 --337	5	+3.0769	9 57 47.5
12	Dec 1--Feb 25	82 --352	25	+3.1395	9 57 50.0
13	Jan 2--May 1	134 --346	13	+3.5932	9 58 8.7
14	Jan 3--Feb 26	120 --299	8	+3.3148	9 57 57.3
15	Feb 25--Mar 23	169 --251	4	+3.0370	9 57 45.8
16	Mar 22--Apr 28	170 --282	9	+3.0270	9 57 45.4
17	Mar 24--Apr 28	140 --252	10	+3.2000	9 57 52.5
18	May 5--Jun 8	180 --287	6	+3.1470	9 57 50.4

Mean rotation period = $9^h57^m54^s.9$

White Spot in Middle of South Equatorial Belt ($\beta''=-13.^{\circ}7$)

Object	1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2/\text{day}$	Rotation Period	S.D.
White Spot	Jan 13--May 27	$340.^{\circ}4$--$356.^{\circ}6$	9	$+0.^{\circ}1203$	$9^h55^m45.^s6$	$\pm1.^s3$

Considerable activity was recorded in the interior of the South Equatorial Belt about 25° preceding the Red Spot during much of the apparition. Past experience suggests that the longitude drift tabulated above pertains to an active area from which a number of white spots formed from time to time. Our charts indicate that the individual spots rapidly faded away while drifting in decreasing longitude with a "normal" rotation period of about $9^h54^m40^s$.

White Spot in Southern Part of Equatorial Zone

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_1/\text{day}$	Rotation Period	S.D.
White Spot	Sep 18--Jan 25	$254.^{\circ}7$--$279.^{\circ}6$	7	+0.1930	$9^h50^m37.^s8$	$\pm0.^s6$

White Spots in Northern Part of Equatorial Zone

Object	1967--1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_1/\text{day}$	Rotation Period	S.D.
1	Sep 18--Jan 25	$268.^{\circ}0$--$255.^{\circ}0$	7	$-0.^{\circ}1012$	$9^h50^m25.^s9$	$\pm0.^s7$
2	Dec 11--Feb 2	142.0--144.1	5	+0.0405	9 50 31.6	±2.0

Mean rotation period = $9^h50^m28.^s7$

These two spots and the white spot in the southern part of the Equatorial Zone were at times very bright and conspicuous on photographs taken in blue light.

White Spots in the Interior of the North Equatorial Belt

Object	1968 Limiting Dates	Limiting Longitudes	N	$\Delta\lambda_2/\text{day}$	Rotation Period	S.D.
1	Mar 16--Mar 25	375°.8--343°.3	3	-3°.6022	$9^h53^m13^s$	$\pm 8^s$
2	Mar 16--Mar 25	384°.0--348°.6	3	-3.9097	9 53 01	±9

Mean rotation period = $9^h53^m7^s$

Spot 1: mean latitude = +12°.3, mean width = 4°.6, mean length = 5°.6

Spot 2: mean latitude = +12°.4, mean width = 4°.5, mean length = 3°.7

Spots on North Edge of North Equatorial Belt (N. Tropical Current)

Object	Limiting Dates 1967--1968	Limiting Longitudes	N	$\Delta\lambda_2/\text{day}$	Rotation Period	S.D.
1(Dp), part 1	Sep 29--Nov 2	30°.2-- 16°.8	7	-0°.391	$9^h55^m24^s.6$	$\pm 2^s.0$
part 2	Nov 2--Dec 25	16.8--350.2	8	-0.498	9 55 20.2	±2.0
part 3	Dec 25--Mar 13	350.2--317.0	22	-0.419	9 55 23.4	±0.5
part 4	Mar 13--Apr 20	317.0--305.9	10	-0.299	9 55 28.3	±2.0
part 5	Apr 20--May 3	305.9--294.1	9	-0.907	9 55 3.4	±5.9
1(Df), part 1	Sep 29--Feb 16	48.9--344.7	27	-0.459	9 55 21.8	±0.2
part 2	Feb 16--Mar 26	344.7--331.6	18	-0.332	9 55 27.0	±0.5
part 3	Mar 26--May 3	331.6--317.8	10	-0.368	9 55 25.5	±2.6
2(white spot)	Sep 29--Mar 23	78.7--335.5	14	-0.587	9 55 16.6	±0.3
3(dark spot)	Dec 3--Mar 25	52.0--343.9	20	-0.603	9 55 15.9	±0.3
4(Wc), part 1	Oct 2--Nov 8	119.0-- 93.2	7	-0.699	9 55 11.9	±0.4
part 2	Nov 8--Jan 24	93.2-- 47.4	19	-0.598	9 55 16.1	±0.4
part 3	Jan 24--Mar 10	47.4--359.3	17	-1.036	9 54 58.1	±0.4
part 4	Mar 10--Mar 26	359.3--346.5	6	-0.796	9 55 8.0	±1.7
part 5	Apr 2--Jun 5	337.7--304.0	16	-0.461	9 55 21.7	±0.8
part 6	Jun 5--Jun 25	304.0--293.7	8	-0.527	9 55 19.0	±0.7

Object	Mean Rotation Period	Mean Latitude	Mean Width	Mean Length
1 (dark bar)	$9^h55^m23\overset{s}{.}0$	$+16\overset{\circ}{.}3 \pm 0\overset{\circ}{.}1$ (4 dates)	$4\overset{\circ}{.}6$ (4 dates)	$17\overset{\circ}{.}8$ (55 dates)
2 (white spot)	9 55 16.6	+19° (estimate)	-----	6.0 (14 dates)
3 (dark spot)	9 55 15.9	$+15\overset{\circ}{.}5 \pm 0\overset{\circ}{.}1$ (6 dates)	$3\overset{\circ}{.}7$ (6 dates)	3.7 (18 dates)
4 (white spot)	9 55 12.2	+19.3 ±0.2 (9 dates)	4.7 (9 dates)	6.0 (73 dates)

Mean rotation period of all spots = $9^h55^m16\overset{s}{.}9$

In the first tabulation above, the drifts of spots 1 and 4 are broken down into a number of sections to reveal the irregularities in their motions. The mean rotation period of each spot for the entire apparition is given in the second tabulation.

White spot 4 was a rather remarkable feature. Its rate of drift in longitude varied considerably during the apparition. For 46 days, from 24 January to 10 March, the spot had a rotation period of $9^h54^m58\overset{s}{.}1 \pm 0\overset{s}{.}4$ which may be the shortest period ever recorded in this latitude (Peek, 1958). A discontinuity in the drift of this spot took place between 26 March and 2 April which indicated a rotation period of $9^h54^m25\overset{s}{.}5$ between these two dates. During this interval, dark spot 3 disappeared and white spot 2 either disappeared or coalesced with white spot 4. Spot 1, which had been a very conspicuous dark streak during much of the apparition, disappeared rather suddenly in early May soon after being overtaken by rapidly moving spot 4.

An interesting conjunction of dark spot 3 (see table above) and the more rapidly-rotating white spot 1 (see table of white spots in the interior of the North Equatorial Belt) occurred on 25 March at longitude (II) $343\overset{\circ}{.}5$. Two days earlier the spots were externally tangent with the white spot extending from latitude $+9\overset{\circ}{.}7$ to $+14\overset{\circ}{.}7$, and the dark spot extending from

+13°.1 to +17°.6. At the time of conjunction the outline of the dark spot appeared unchanged, while the white spot appeared crescent-shaped with the dark spot projecting into it. This could indicate that the dark spot was at a higher level than the white spot, or that they were at the same level with the white spot being deflected by the dark spot.

A conspicuous but short-lived dark spot was visible on the north edge of the North Equatorial Belt at latitude +16°.4 and longitude (II) 31°.6 between 12 and 17 April 1968. The spot had a length of 8° and a width of 6°. No definite spot could be seen near this position on either 9 or 24 April even though the photographs were of good quality. The region, however, appeared to be quite active and a diffuse spot had appeared intermittently in the extrapolated longitude during February and March. Many spots on Jupiter appear to be manifestations of longer-enduring disturbances at a lower level in the atmosphere. Individual spots will fade away, but other spots may later form in the same position.

<u>The Oscillating Spot on the NNTBs (N. N. Temperate Current B)</u>

During January 1968 a small dark spot on the south edge of the NNTB was found to be moving in the direction of decreasing System II longitude at the very rapid rate of nearly 3° per day. This unusual drift clearly indicated that the spot was moving in the rarely observed N. N. Temperate Current B which had been inactive since 1945.

This remarkable current was first discovered by Hargreaves (Phillips, 1937) during the apparition of 1929-30 when 7 spots gave a mean rotation period of $9^h53^m54^s$. The only other outbreak of spots in this current was observed during five consecutive apparitions from 1940 to 1945 (Peek, 1958).

There is some evidence that activity on the NNTBs is in some way related to activity on the NTBs (Peek, 1944). The outbreak of spots on the NNTBs seem to occur concurrently with, or a few years after, the outbreak of spots on the NTBs. Present activity seems to confirm this rule. Activity was observed on the NTBs in 1964-65 (Reese and Smith, 1966), and there was activity on the NNTBs in 1968[3].

When all the measured longitudes of the NNTBs spot had been plotted on a graph, it became obvious that the spot was oscillating in longitude. Since the oscillation appeared to resemble a sine curve, the observations were submitted to a general least squares computer program of the form:

$$\lambda_2 = a + bt + c \sin \Theta t$$

where t is the time in days from t_o.

t_o is the time when the least squares position of the spot was on the axis of the sine curve and moving toward increasing longitude.

a is the System II longitude of the least squares position of the spot at t_o.

b is the slope or daily drift rate of the sine curve axis in System II.

c is the amplitude of the oscillation in degrees of longitude.

Θ is 360° divided by the period of the oscillation in days.

The computer program found the least squares values of t_o and Θ by repeatedly incrementing them, computing the standard deviation from the residuals, and finally accepting the values which gave the smallest standard deviation. The equation of the spot's motion is longitude is then:

$$\lambda_2 = 321^{\circ}\!.73 - 2^{\circ}\!.827t + 3^{\circ}\!.441 \sin 5^{\circ}\!.418t,$$

where t is the time elapsed in days from 1968, January 25.8. From this equation we find that the period of the oscillation was 66.4 days, and the rotation period of the axis was $9^h53^m44^s.9$.

The daily drift of the spot in System II longitude at any time, t, was $-2^\circ.827 + 0^\circ.325 \cos 5.418\, t$. Due to the oscillating component in the motion, the rotation period varied from $9^h53^m32^s$ to $9^h53^m58^s$. The spot underwent a maximum acceleration of $\pm 5.2 \times 10^{-6}$ m/sec^2.

The latitude of the spot remained nearly constant at $+35^\circ.5$ throughout the interval of observation; however, a linear least squares solution indicates that the latitude gradually increased from $+35^\circ.2 \pm 0^\circ.1$ on 13 January to $+35^\circ.8 \pm 0^\circ.1$ on 25 March.

Observational and least squares data of the NNTBs spot are summarized in Table II and graphically depicted in Figure 6. In Figure 6 the observed and computed longitudes have been diminished by the algebraic sum of the first two terms in the above equation so that the presentation of the oscillation is normal to the computed axis.

We thank observers C. J. Banos, A. S. Murrell, and T. P. Pope for the photographs used in this study; R. L. Fritz, R. B. Minton, and E. M. Ingraham for the illustrations; and the New Mexico State University Computer Center for time on the Control Data 3300 and the IBM 1130 computers.

The work reported here was supported by the National Aeronautics and Space Administration under Grants NGL-32-003-001 and NGR-32-003-027.

REFERENCES

Peek, B. M. (1944). Thirty-second Report of the Jupiter Section. Mem. Brit. Astron. Assoc. 35, Part 3, 11.

Peek, B. M. (1958). "The Planet Jupiter." Macmillan, New York.

Phillips, T. E. R. (1937). Twenty-eighth Report of the Jupiter Section. Mem. Brit. Astron. Assoc. 32, Part 4, 13.

Reese, E. J. (1967). Jupiter's Great Red Spot and three white ovals. Sky and Telescope, 34, 185-186.

Reese, E. J. (1968). An old and a new dark streak on Jupiter. Sky and Telescope, 35, 258-259.

Reese, E. J. and Smith, B. A. (1966). A rapidly moving spot on Jupiter's North Temperate Belt. Icarus 5, 248-257.

Reese, E. J. and Smith, B. A. (1968). Evidence of vorticity in the Great Red Spot of Jupiter. Icarus 9, 474.

Reese, E. J. and Solberg, H. G. (1966). Recent measures of the latitude and longitude of Jupiter's Red Spot. Icarus 5, 266.

Solberg, H. G. (1969). Jupiter's Red Spot in 1967-68. Icarus (in press).

Solberg, H. G. and Reese, E. J. (1969). Photographic measurements of Jovian features, 1960-1967. New Mexico State University Observatory TN-701-69-25.

FOOTNOTES

[1]Any change in the height of the spot in the relatively shallow Jovian atmosphere would appear to be inadaquate to account for the difference between the observed and computed rotation periods.

[2]The rotational velocity of a Jovian spot in meters per second is found as follows:

$$\text{Rotational velocity} = [45{,}226 - 51.951\,(\pm d)]\;0.2777\cos\beta',$$

where β' is the mean Jovian latitude, and d is the daily drift of the spot in System II longitude. Zenographic latitude, β'', and mean Jovian latitude, β', are related as follows:

$$\tan\beta'' = \tan\beta'/1.0713$$

[3]After reexamining some of our plates taken in 1965-66, we have found at least two spots on the NNTBs which obviously belonged to the N. N. Temperate Current B. The better observed spot was at zenographic latitude $+35^{\circ}.1$ and moved from longitude (II) 359° on 25 December 1965 to 234° on 10 February 1966 with a mean rotation period of $9^h53^m52^s$.

TABLE I

MEAN ZENOGRAPHIC LATITUDES (β") OF JOVIAN BELTS IN 1967-68

N = Number of dates on which plates were measured.

INTERVAL →	30 Sep 67--30 Nov 67			5 Dec 67--16 Feb 68			5 Mar 68--11 Jun 68			Mean for 1967-68		
Belt	β"	S.D.[a]	N	β"	S.D.[a]	N	β"	S.D.[a]	N	N	β"	cos β'[b]
SPB	----	----	-	-67°.4	±2°.4	2	----	----	-	2	-67°.4	.407
SSSTB	----	----	-	-55.2	±0.2	2	----	----	-	2	-55.2	.597
SSTB	-43°.2	±0°.0	2	-43.3	±0.7	5	-42°.5	±3°.0	2	9	-43.1	.753
STeZB	----	----	-	-37.6	±0.3	3	----	----	-	3	-37.6	.812
s/STB	-33.1	±0.1	6	-33.2	±0.1	7	-33.0	±0.2	8	21	-33.1	.854
n/STB	-26.6	±0.2	6	-27.1	±0.2	7	-27.4	±0.3	8	21	-27.1	.902
STrZB	----	----	-	-24.3	±0.1	2	-24.4	±0.5	3	5	-24.4	.921
s/SEBs	-21.5	±0.2	6	-21.2	±0.2	6	-21.1	±0.3	7	19	-21.2	.940
n/SEBs	-15.6	±0.3	6	-15.8	±0.3	6	-15.6	±0.4	7	19	-15.7	.967
s/SEBn	-11.8	±0.2	6	-11.4	±0.2	7	-11.0	±0.2	8	21	-11.4	.983
n/SEBn	- 7.0	±0.2	6	- 6.8	±0.1	7	- 7.1	±0.1	8	21	- 7.0	.993
s/EB	- 2.9	±0.1	6	- 2.9	±0.1	7	- 3.4	±0.3	7	20	- 3.1	.999
n/EB	+ 3.6	±0.2	6	+ 3.0	±0.2	7	+ 3.4	±0.1	7	20	+ 3.3	.999
s/NEBs	+ 7.3	±0.1	6	+ 7.1	±0.1	7	+ 7.0	±0.2	7	20	+ 7.1	.993
n/NEBs	----	----	-	+11.2	±0.3	4	+10.8	±0.1	7	11	+10.9	.984
s/NEBn	----	----	-	+14.7	±0.3	4	+15.3	±0.2	7	11	+15.1	.970
n/NEBn	+21.2	±0.3	6	+21.1	±0.1	7	+20.8	±0.1	7	20	+21.0	.941
NTrZB	----	----	-	+23.7	----	1	----	----	-	1	+23.7	.925
s/NTB	+26.2	±0.1	5	+25.9	±0.4	8	+25.5	±0.3	7	20	+25.8	.911
n/NTB	+31.7	±0.3	5	+31.7	±0.3	8	+31.5	±0.4	7	20	+31.6	.867
s/NNTB	+36.6	----	1	+35.8	±0.7	3	+35.3	±0.1	2	6	+35.8	.830
NNTB	+38.2	----	1	+37.6	±0.8	3	+38.5	±1.9	2	6	+38.0	.808
NNNTB	+44.9	----	1	+44.6	±0.7	3	+43.6	----	1	5	+44.5	.737
NPB	----	----	-	+59.5	----	1	----	----	-	1	+59.5	.534

[a]Measuring errors and real variations in the latitude of a belt from one date to another contribut to this standard deviation.

[b]Cos β' is the factor by which the equatorial radius of Jupiter must be multiplied to obtain the radius of rotation for a given zenographic latitude, β". (tan β' = tan β"/1.0713).

TABLE II

THE OSCILLATING SPOT ON THE NNTBs (N. N. TEMPERATE CURRENT B)

Date 1968	Observed Longitude II	Probable Error	Computed Longitude II of Sine Curve	Dev. O-C	Computed Longitude relative to axis of sine curve	Zenographic Latitude
Jan 13.34	353°.7	±0°.2	353°.8	-0°.08	-3°.19	+35°.3
22.42	330.5	±0.3	330.2	0.29	-1.05	---
24.48	324.9	--	325.0	-0.17	-0.41	+35.6
25.30	322.7	±0.1	323.0	-0.26	-0.14	+35.0
29.40	313.1	±0.2	312.7	0.43	1.14	---
Feb 5.42	294.1	±0.4	294.6	-0.47	2.90	+35.6
16.16	264.8	±0.2	264.4	0.37	3.10	+35.6
18.20	258.4	--	258.3	0.09	2.75	---
20.24	252.1	±0.1	252.1	0.01	2.30	+35.1
25.22	236.6	±0.2	236.6	0.02	0.89	+35.6
27.29	230.0	±0.1	230.1	-0.06	0.23	---
Mar 6.15	204.8	±0.2	205.5	-0.66	-2.16	---
8.15	199.7	±0.5	199.4	0.28	-2.63	---
13.15	184.3	±0.2	184.5	-0.20	-3.36	---
14.38	181.1	±0.2	181.0	0.18	-3.42	+35.8
15.21	178.9	±0.3	178.6	0.31	-3.44	---
25.11	152.2	±0.4	151.9	0.31	-2.15	+35.8
27.11	146.8	±0.3	146.8	0.03	-1.61	---
29.20	141.1	±0.2	141.5	-0.42	-0.99	---

Standard deviation of a single observed longitude from computed sine curve = ±0°.30

Mean latitude of NNTBs Spot = +35°.5 ±0°.1 (9 dates)

Mean width in latitude of Spot = 3°.3 ±0°.3 (9 dates)

Mean length in longitude of Spot = 5°.3 ±0°.3 (19 dates)

Mean drift rate of Spot = -2°.8274 per day in System II

Mean rotation period = $9^{h}53^{m}44^{s}.9$

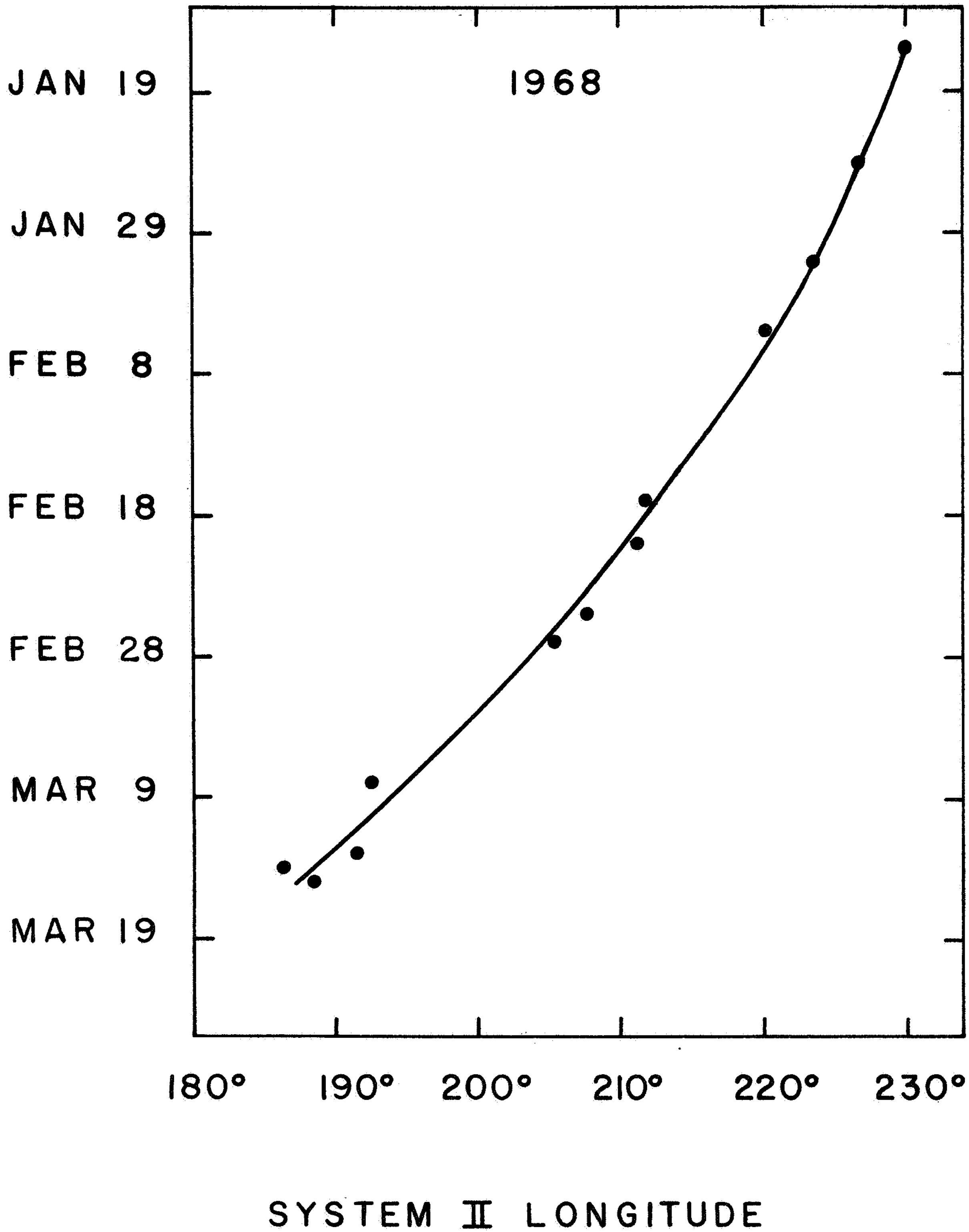

Fig. 1. A yellow spot in the South Polar Region exhibited an accelerating motion in longitude as it moved southward in latitude.

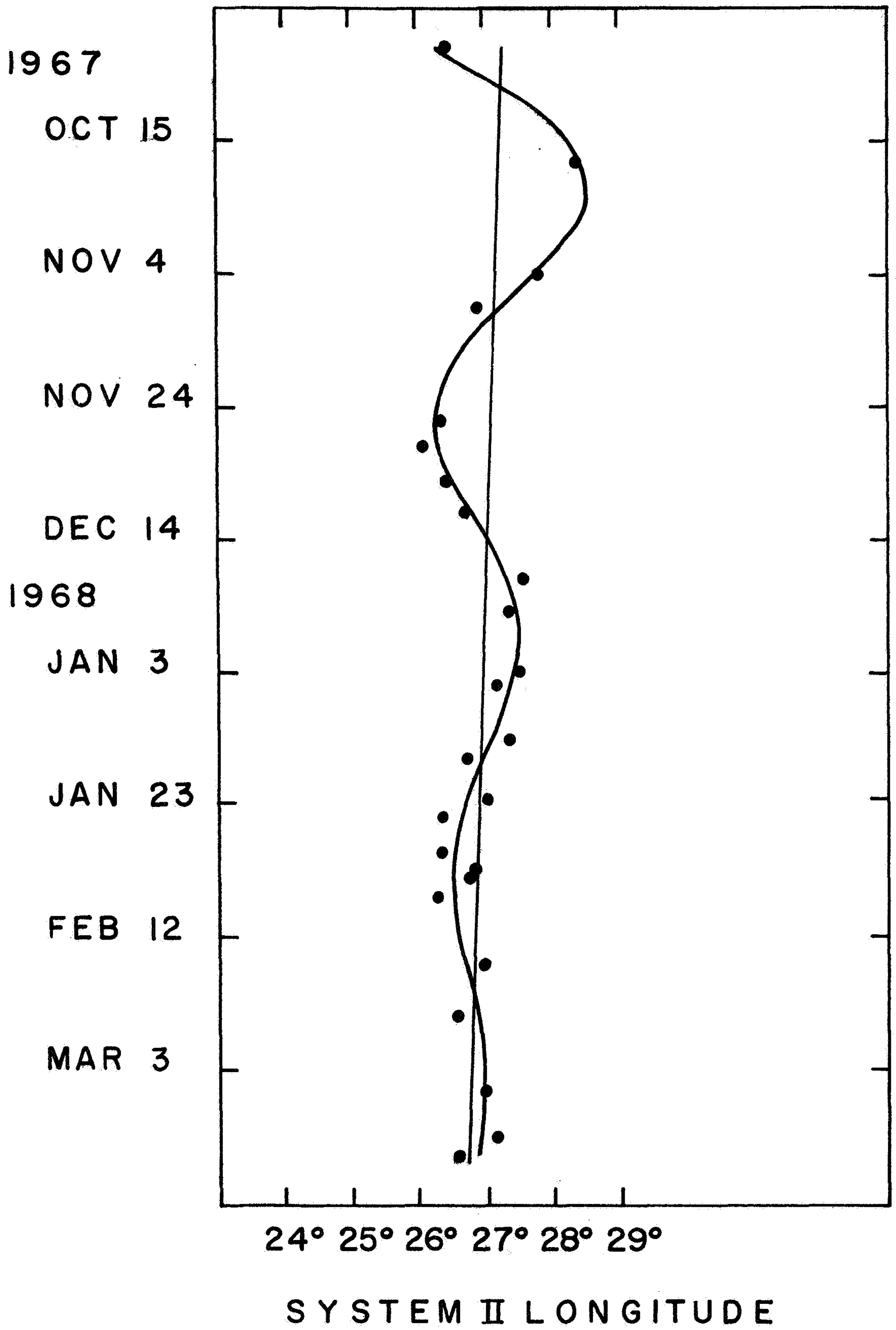

Fig. 2. The drift in longitude of the center of the Red Spot Hollow resembled a damped harmonic oscillation.

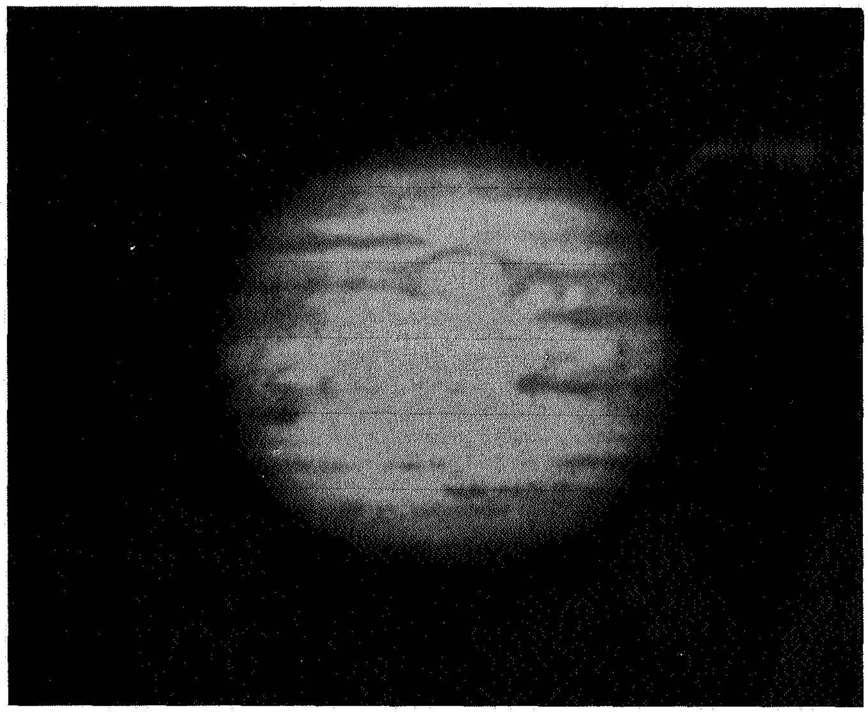

Fig. 3. Jupiter in red light, 16 February 1968, 0655 UT showing the bright Red Spot Hollow and its dark border. Just south of the Hollow is BC, one of the three long-lived bright ovals on the south edge of the South Temperate Belt. South is at the top and the direction of rotation is from right to left. 61-cm reflector.

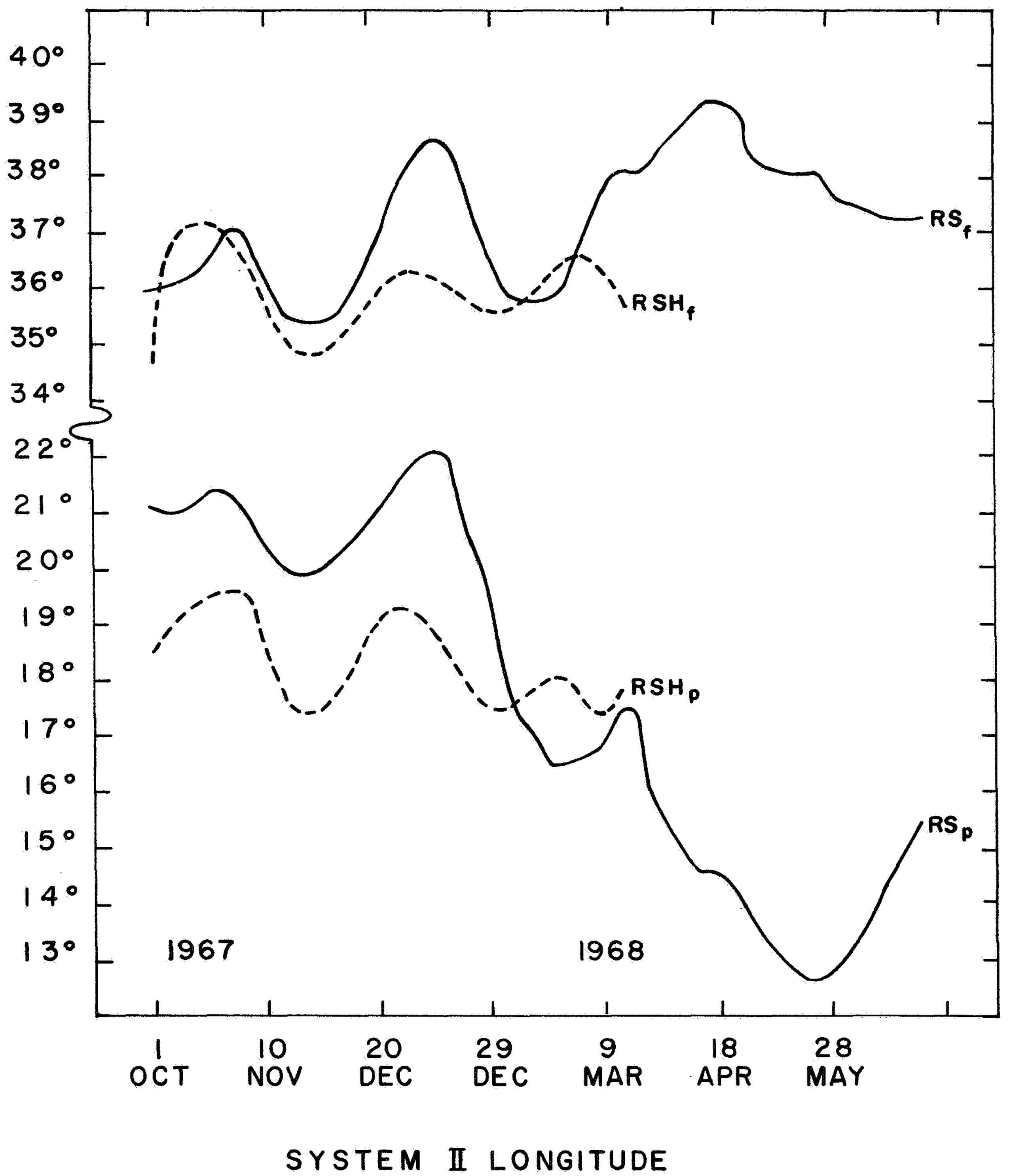

Fig. 4. Oscillations in longitude of the preceding and following ends of the Red Spot (solid lines) and the Red Spot Hollow (broken lines) in 1967-68.

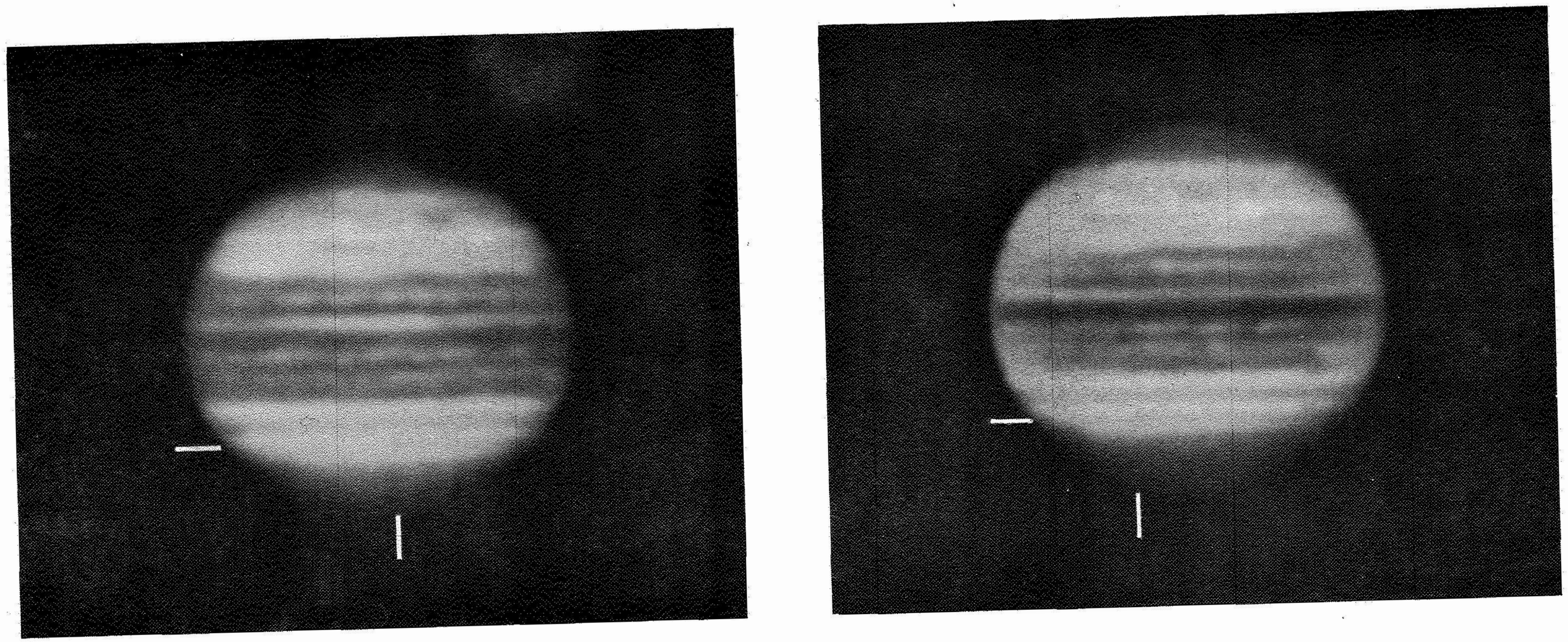

Fig. 5. Two photographs of Jupiter taken with the 61-cm reflector showing the small, dark oscillating spot on the NNTBs. Left: Jupiter in blue light, 25 February 1968, 0512 UT, ω_2 232°. The small, dark NNTBs spot is visible very near the central meridian. The dark streak in the South Temperate Belt precedes the central meridian. Right: Jupiter in ultraviolet light, 27 February 1968, 0715 UT, ω_2 247°. In this view, the NNTBs spot precedes the central meridian. Notice the extreme darkness of the Equatorial Band in ultraviolet light.

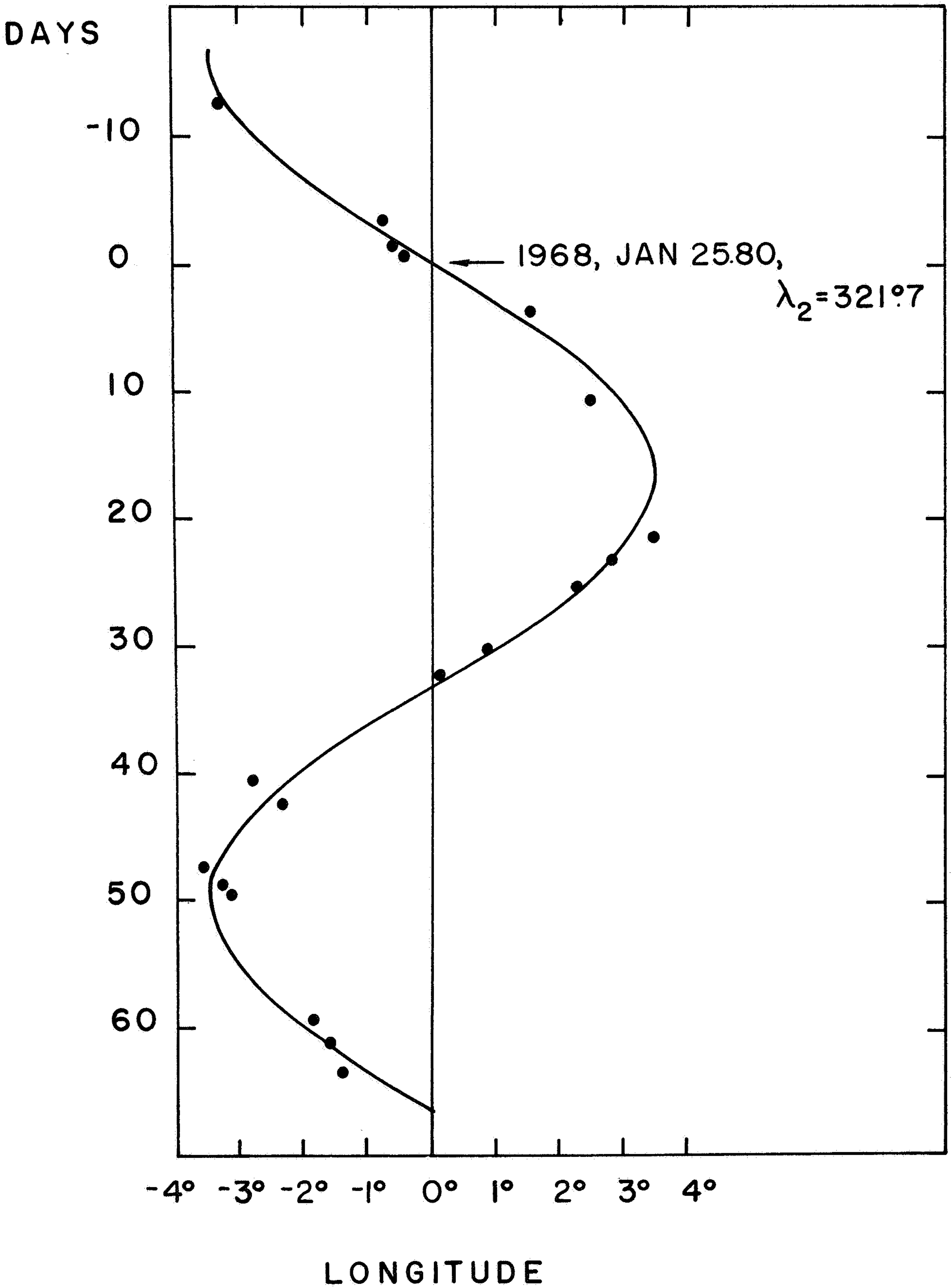

Fig. 6. The oscillating spot on the south edge of the NNTB in 1968.