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# A THREE-MONTH OSCILLATION IN THE LONGITUDE OF JUPITER'S RED SPOT

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ABSTRACT

Photographic measurements of Jupiter's Red Spot show that it oscillated semiregularly between 1963 and 1968; the oscillation had a mean period of 90.0 days and a mean amplitude of $0^\circ.8$. No comparable oscillation has ever been observed in the Jovian atmosphere.

## INTRODUCTION

Since 1963, Jupiter's Red Spot has been photographed on every opportunity at the New Mexico State University Observatory. This continuing program, the first of its kind ever attempted, has resulted in about 1200 photographic plates of the Red Spot during five apparitions. Of this number, 472 plates, taken in blue light on 469 separate dates, were measured for the longitude of the Red Spot. The position of the Red Spot can be measured from photographic plates with a standard deviation of about $\pm 0^\circ.22$, which is a considerable improvement over earlier measurement techniques. The procedure used in measuring the Red Spot is discussed elsewhere (Reese and Solberg, 1966).

During the five apparitions that the Red Spot was extensively photographed, it oscillated in longitude (Fig. 1). The oscillations were semiregular, having a mean period of 90.0 days and a mean amplitude of $0^\circ.8$.

## OBSERVATIONS

As seen in Fig. 2, the Red Spot has varied irregularly in longitude for quite some time, but only since 1961 has this variation been revealed to be periodic. It is possible, however, that a careful analysis of earlier visual transit observations, using data not available to the writer, will show that the periodic oscillation existed prior to 1961. The first observations used in this study which show the periodic oscillation are mean Red Spot longitudes during 12-day intervals obtained from several hundred visual transit observations made during the 3 apparitions between 1961 and 1963 (Reese, 1962; 1963; 1964). Mean periods of the longitude oscillation derived from these observations are presented in Table I. In the remainder of this paper only photographic measurements will be discussed; the original measurements are available elsewhere (Reese and Solberg, 1966; Solberg, 1968a; 1968b; 1968c). Basic information on the behavior of the Red Spot during each of the five apparitions is given in Table II.

The scatter of the original longitude determinations was reduced by averaging each measurement with the two measurements preceding and following it. The times of maxima and minima were estimated from graphs of the smoothed longitudes; the accuracy of this method is about $\pm 2$ days (See Table III). Mean periods of the oscillation for each apparition (Table I) and for the entire interval (Table IV) were determined from the times of maxima and minima using the method of least squares. This method gives a mean period for the Red Spot center of $90^{d}.09 \pm 1^{d}.94$ (s.d.).

If we assume the longitude of the center of the Red Spot to vary sinusoidally with a period of $90^{d}.0$ and an amplitude of $0^{\circ}.8$, then the velocity of the Red Spot would also vary sinusoidally, with a maximum value of 0.750 m/sec. This agrees well with the mean observed maximum velocity of 0.695 $\pm$ 0.074 m/sec. Thus assuming the sinusoidal variation to be a good approximation of the Red Spot's actual motion, we find the maximum acceleration of the spot to be about $6x10^{-7}$ m/sec$^2$.

As an alternative procedure, secular changes in the Red Spot's longitude were removed by considering the longitudes for each apparition as deviations from the least squares drift of the Spot during that apparition (Fig. 3). By this method, the mean period for the center is $90^{d}.02 \pm 1^{d}.86$.

We have determined statistically that the observed difference between the two periods was almost surely caused by chance. Similarly, we can conclude that the difference between the mean period of the preceding end ($90^{d}.4$) and the following end ($89^{d}.5$) is not significant.

As mentioned above, the standard deviation of the mean period for the center is $\pm 1^{d}.9$. In an attempt to reduce the standard deviation, the period was assumed to vary sinusoidally with a period of 2.0 years and an amplitude of 4.7 days. These values were estimated from a "best fit" of the data. The standard deviation was reduced to $\pm 1^{d}.6$. This is not a significant reduction of the standard deviation, however, so we can infer that the reality of any regular variation in the period is doubtful.

If the Red Spot oscillation were caused by a wave propagating along the STrZ, we would expect the maxima and minima at one end of the Red Spot to occur a few days before the corresponding events at the other end of the Spot, assuming the two ends to move independently. A test of this hypothesis shows that events occurred, on the average, 4.2 days earlier at the preceding end than at the following end, with a probability of 0.12 of being due to chance. A probability of chance greater than 0.05 is generally accepted as indicating a lack of significance, so we may assume that the hypothesis was not verified. Furthermore, if we accepted the hypothesis, we would probably expect the Red Spot to oscillate with a period consistent with the rotation rate of spots on the south edge of the SEBs, since they approach toward the preceding end of the Red Spot. But the 90-day period is actually more consistent with spots travelling along the north edge of the STB--spots moving 360° in 90 days in the direction of decreasing longitude have rotation periods of $9^h52^m57^s$, while retrograding spots with the same velocity have periods of $9^h58^m26^s$. Typical periods for SEBs spots during the observed interval were of the order of $9^h58^m00^s$, while STB spots had periods near $9^h53^m00^s$.

## OTHER OSCILLATIONS

Oscillating spots on Jupiter are rare--Peek (1958) lists only two, and no other oscillating spots were found after a search of available visual observations. Our photographic observations add only four spots to the list (Table V). It is interesting to note that only two of the spots, the Red Spot and the oscillating spot of 1940-41, were observed to oscillate through more than one cycle, and that the Red Spot oscillation is by far the more convincing. The oscillation of the Red Spot reported in this paper is thus apparently the most pronounced in the history of Jovian observation.

## CONCLUDING REMARKS

It was suspected at first that the observed Red Spot oscillation could be a result of systematic errors or an incorrect phase exaggeration correction. Such an explanation is untenable, however. For one thing, the same sequence of events is not exactly repeated during each apparition--for example, at opposition the longitude of the Red Spot is just as likely to be at a minimum as at a maximum. Furthermore, other extensively measured spots, which would also be expected to show the results of systematic errors, show no trace of oscillatory behavior. Thus we may conclude that the oscillation of the Red Spot is indeed real. The significance of the observed oscillation should not be underestimated; this is one of the rare instances in which a predictable type of behavior has occurred consistently for such a length of time on Jupiter.

## ACKNOWLEDGMENTS

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TABLE I

PERIOD OF OSCILLATION DURING VARIOUS APPARITIONS

RED SPOT CENTER

| | Visual (With Secular Variation) | | | Photographic (With Secular Variation) | | | Photographic (Without Secular Variation) | | |
|---|---|---|---|---|---|---|---|---|---|
| Appa-rition | Period | S.D. Mean | N* | Period | S.D. Mean | N | Period | S.D. Mean | N |
| 61-62 | $89\overset{d}{.}2$ | $\pm2\overset{d}{.}0$ | 6 | | | | | | |
| 62-63 | 119.5 | 0.8 | 4 | | | | | | |
| 63-64 | 104.4 | 2.1 | 4 | $88\overset{d}{.}0$ | $\pm6\overset{d}{.}2$ | 3 | $91\overset{d}{.}2$ | $\pm3\overset{d}{.}7$ | 4 |
| 64-65 | | | | 87.9 | 2.7 | 6 | 89.1 | 3.0 | 6 |
| 65-66 | | | | 84.7 | 1.6 | 7 | 86.8 | 2.5 | 6 |
| 66-67 | | | | 103.0 | 2.7 | 5 | 105.0 | 1.3 | 5 |
| 67-68 | | | | 82.3 | 4.8 | 6 | 81.0 | 4.5 | 6 |

*N = Number of maxima and minima observed.

TABLE II

RED SPOT POSITIONS AND DIMENSIONS, 1963-68

| Apparition | Opposition Date | Limiting Dates | $9^h55^m$+ Rotation Period | Mean Length | Number of Plates | Mean β" | Mean Width | Number of Plates |
|---|---|---|---|---|---|---|---|---|
| 63-64 | 8 Oct 1963 | 2 May - 28 Mar | $40\overset{s}{.}6$ | 23°7 | 50 | -22°5 | 12°5 | 47 |
| 64-65 | 13 Nov 1964 | 10 Jun - 2 May | 41.5 | 23.4 | 79 | -22.1 | 12.0 | 61 |
| 65-66 | 18 Dec 1965 | 1 Jul - 4 Jun | 41.2 | 22.5 | 143 | -22.3 | 10.9 | 97 |
| 66-67 | 20 Jan 1967 | 15 Aug - 13 Jun | 40.5 | 16.0 | 108 | -23.1 | 7.6 | 78 |
| 67-68 | 20 Feb 1968 | 12 Sep - 17 Jul | 40.5 | 19.8 | 90 | -23.0 | 10.0 | 59 |

TABLE III

DATES OF MAXIMA & MINIMA (Julian Date - 2,430,000)

| Preceding | | Center (without secular variation) | | Center (with secular variation) | | Following | |
|---|---|---|---|---|---|---|---|
| Event# | Julian Date | # | J.D. | # | J.D. | # | J.D. |
| | | | | | | 1 | 8232 |
| 1 | 8225 | | | | | 2 | 8279 |
| 2 | 8293 | 1 | 8299 | 1 | 8294 | 3 | 8298 |
| 3 | 8327 | 2 | 8326 | 2 | 8323 | 4 | 8325 |
| 4 | 8388 | 3 | 8387 | 3 | 8383 | 5 | 8384 |
| 5 | 8424 | | | 4 | 8426 | 6 | 8420 |
| | | 8 | 8608 | 8 | 8606 | | |
| 10 | 8632 | 9 | 8635 | 9 | 8635 | 11 | 8651 |
| 11 | 8676 | 10 | 8683 | 10 | 8677 | 12 | 8709 |
| 12 | 8725 | 11 | 8730 | 11 | 8735 | 13 | 8738 |
| 13 | 8782 | 12 | 8782 | 12 | 8782 | 14 | 8788 |
| 14 | 8814 | 13 | 8818 | 13 | 8818 | 15 | 8816 |
| 17 | 8977 | 16 | 8978 | | | 18 | 8972 |
| 18 | 9013 | 17 | 9013 | 17 | 9011 | 19 | 9009 |
| 19 | 9058 | 18 | 9056 | 18 | 9052 | 20 | 9076 |
| 20 | 9088 | 19 | 9094 | 19 | 9090 | 21 | 9094 |
| 21 | 9151 | 20 | 9149 | 20 | 9144 | 22 | 9141 |
| 22 | 9181 | 21 | 9186 | 21 | 9192 | 23 | 9187 |
| 23 | 9226 | 22 | 9227 | 22 | 9220 | 24 | 9238 |
| 27 | 9412 | 26 | 9392 | 26 | 9390 | 28 | 9384 |
| 28 | 9450 | 27 | 9459 | 27 | 9450 | 29 | 9470 |
| 29 | 9497 | 28 | 9497 | 28 | 9496 | 30 | 9498 |
| 30 | 9556 | 29 | 9554 | 29 | 9551 | 31 | 9559 |
| 31 | 9601 | 30 | 9602 | 30 | 9602 | 32 | 9602 |
| 35 | 9792 | 34 | 9794 | 34 | 9794 | 36 | 9795 |
| 36 | 9820 | 35 | 9820 | 35 | 9814 | 37 | 9822 |
| 37 | 9870 | 36 | 9868 | 36 | 9868 | 38 | 9866 |
| 38 | 9910 | 37 | 9907 | 37 | 9902 | 39 | 9898 |
| 39 | 9934 | 38 | 9932 | 38 | 9932 | 40 | 9962 |
| 40 | 9999 | 39 | 10,007 | 39 | 10,000 | | |

TABLE IV

MEAN PERIOD OF RED SPOT OSCILLATION, 1963-68

| | Period | S.D. Mean | Number of Maxima & Minima | Interval |
|---|---|---|---|---|
| | WITHOUT SECULAR VARIATION | | | |
| Center | $90^{d}.02$ | $\pm 1^{d}.86$ | 27 | $1708^{d}$ |
| | WITH SECULAR VARIATION | | | |
| Preceding | $90^{d}.40$ | $\pm 1^{d}.88$ | 28 | $1774^{d}$ |
| Center | 90.09 | 1.94 | 27 | 1706 |
| Following | 89.48 | 2.48 | 28 | 1730 |

TABLE V

OSCILLATING SPOTS

| Apparition | Description | Location | Period | Amplitude | Number of Observations | Comments |
|---|---|---|---|---|---|---|
| 1940-41 | d. spot | S/STrZ | $72^d$ | 5° | 24 | Damped Oscillation |
| 1941-42 | d. spot | S/STrZ | var. | 5° | 31 | Variable latitude, period steadily increased |
| 1964-65 | d. spot | NTBs | $300^d$ | 4° | 51 | Only 1/2 cycle observed |
| 1965-66 | w. spot | S/SSTB | $67^d$ | 1° | 10 | Uncertain |
| 1967-68 | d. spot | S/NNTB | $66^d$ | 3°.4 | 20 | |
| 1961-68 | RS | STrZ | $90^d$ | 0°.8 | 472 | |

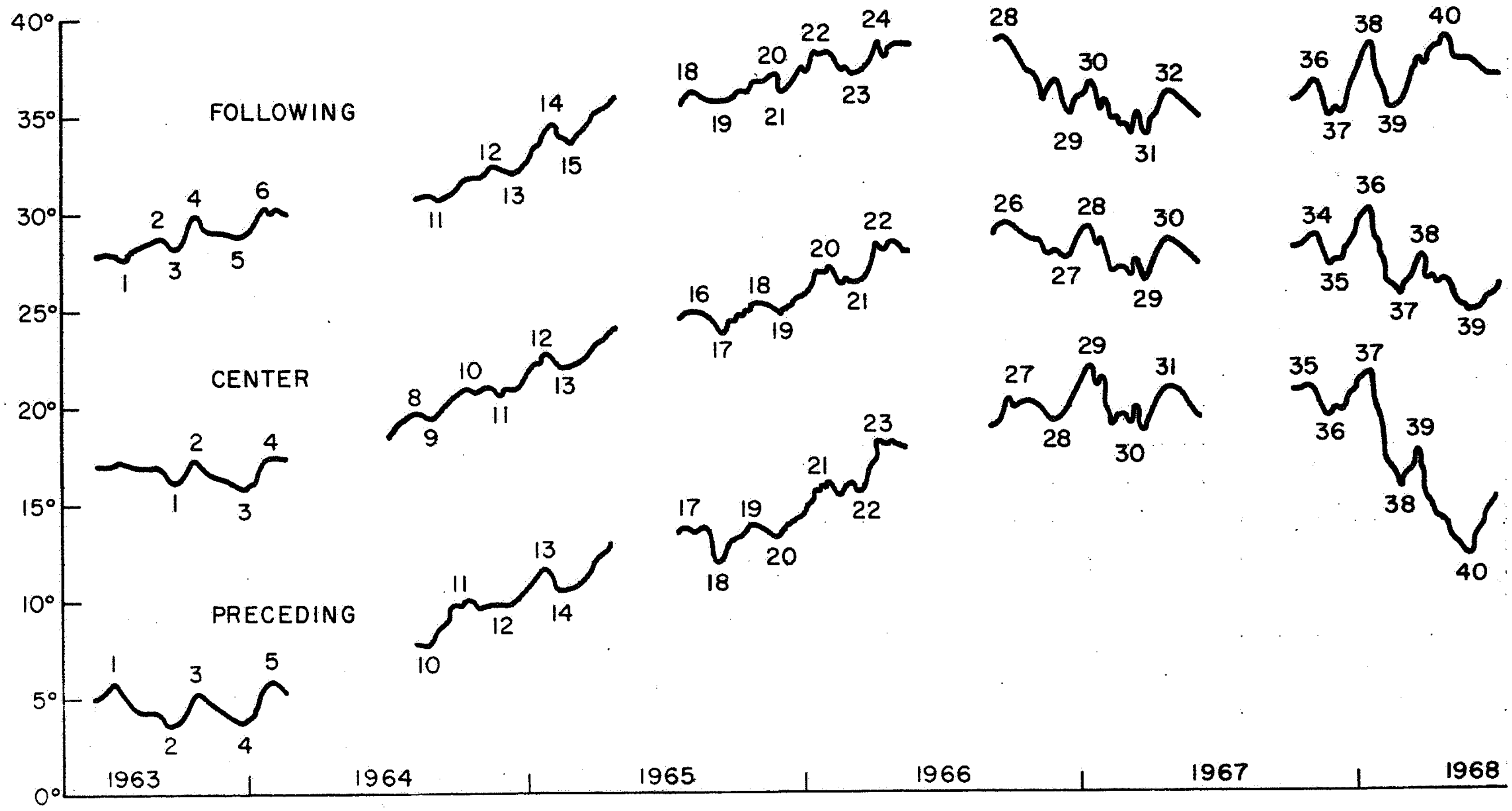


FIG. 1

The longitudinal oscillation of the two ends and center of the Red Spot is semiregular, with a mean period of about 90 days. The maxima and minima are numbered in a manner consistent with this period.

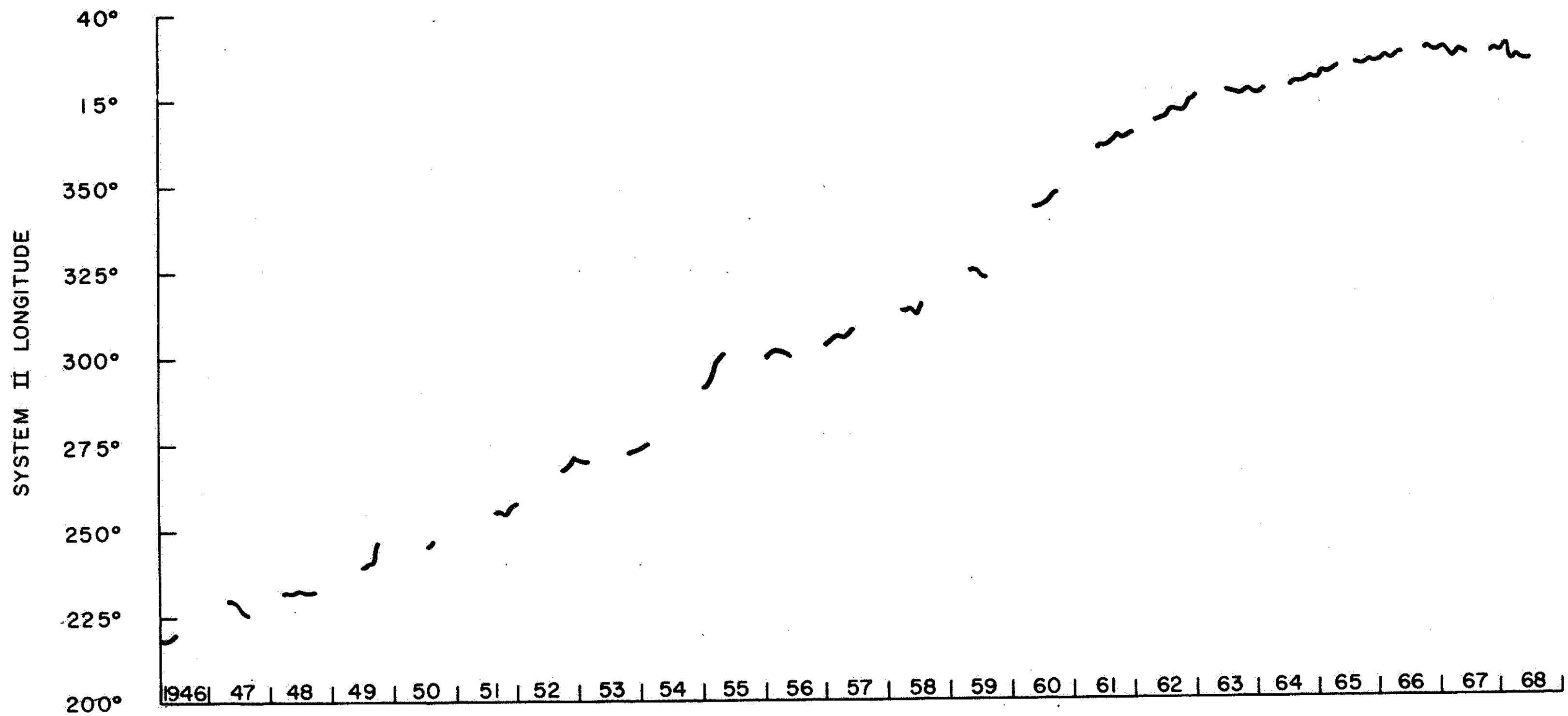


FIG. 2

Between 1946, when this series of observations began, and 1960 the Red Spot apparently moved irregularly in System II longitude. Between 1969 and 1968, the Red Spot oscillated in a semiregular manner. All observations between 1946 and 1962 are visual, and were made by E. J. Reese. The remaining observations were made photographically at the New Mexico State University Observatory.

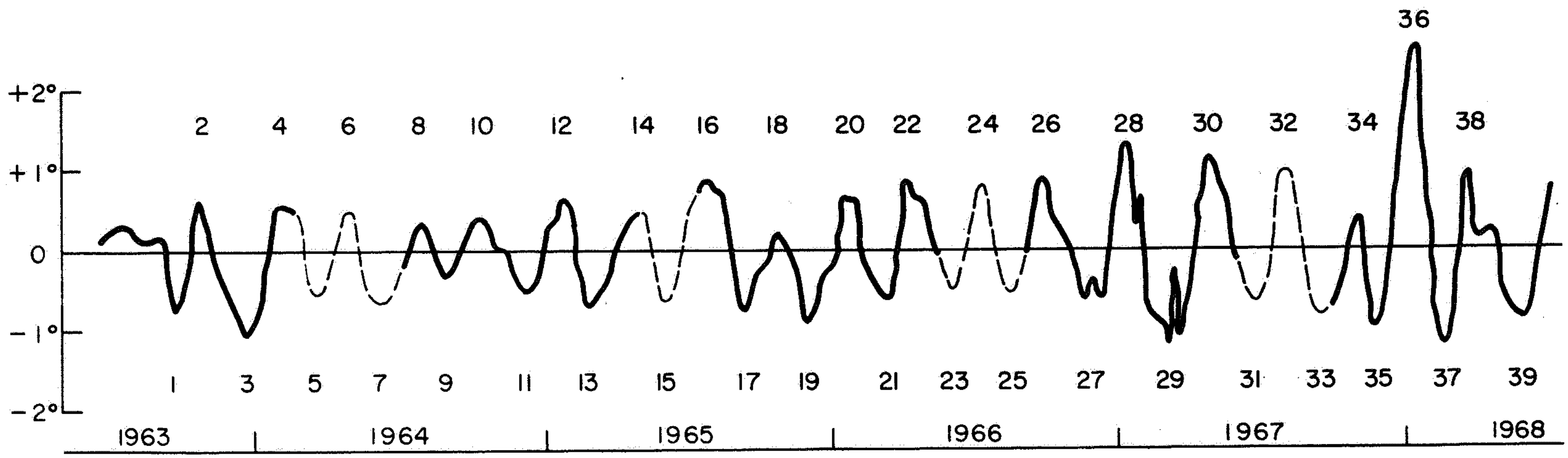


FIG. 3

Secular changes in the Red Spot's longitude have been removed by calculating the least squares drift of the Red Spot center for each of the five apparitions. Longitudes are plotted as deviations from the least-square solutions. The heavy line represents the observed oscillation, while the dashed line is the interpolated curve.