A NEW DETERMINATION OF JUPITER'S RADIO ROTATION PERIOD

C. A. Higgins*, T. D. Carr*, and F. Reyes*

Abstract

A new measurement of the radio period of rotation of Jupiter is presented. The measurement was made from the University of Florida and University of Chile database of Jovian decametric observations at frequencies of 18, 20, and 22 MHz between 1957 and 1994. The mean of our 24 independent measurements was $9^h55^m29^s.685$, and the standard deviation of the mean was $0^s.0034$. We found that our new result is highly significantly different (7.4σ) from the currently accepted System III (1965) Jovian rotation period value. We also found that the rotation period is not drifting in excess of 27 milliseconds per year as measured by our method.

1 Introduction

There has been a long history of measurements for the determination of a precise rotation period for the planet Jupiter. Our report is essentially a review of our latest results on the System III rotation period published by Higgins et al. [1996]. The System I and System II periods were established in the late 1800s by measuring the motions of optical features within the atmosphere [Marth, 1885]. System I and II correspond to the average motions of the features near the planets equator and temperate zones, respectively. The System III period represents the period of rotation of the non-thermal radio sources and was coined in the late 1950s after the radio emission had been discovered [Carr et al., 1958]. Figure 1 is an overview of the three rotation systems and their latest accepted values.

The method for calculating Jupiter's rotation period is to establish an arbitrary reference point in the longitude system of Jupiter's central meridian (CML). Monitoring the longitudinal position of an observed feature over a period of time reveals whether that feature drifts in position with respect to the reference. If the observed feature were to remain at the same CML after a period of time, it would be concluded that the rotation period of the feature is the same as the reference system. A positive drift in CML would indicate that its true rotation period is greater than the reference period, and vice versa.

*Department of Astronomy, University of Florida, Gainesville, FL 32611, USA

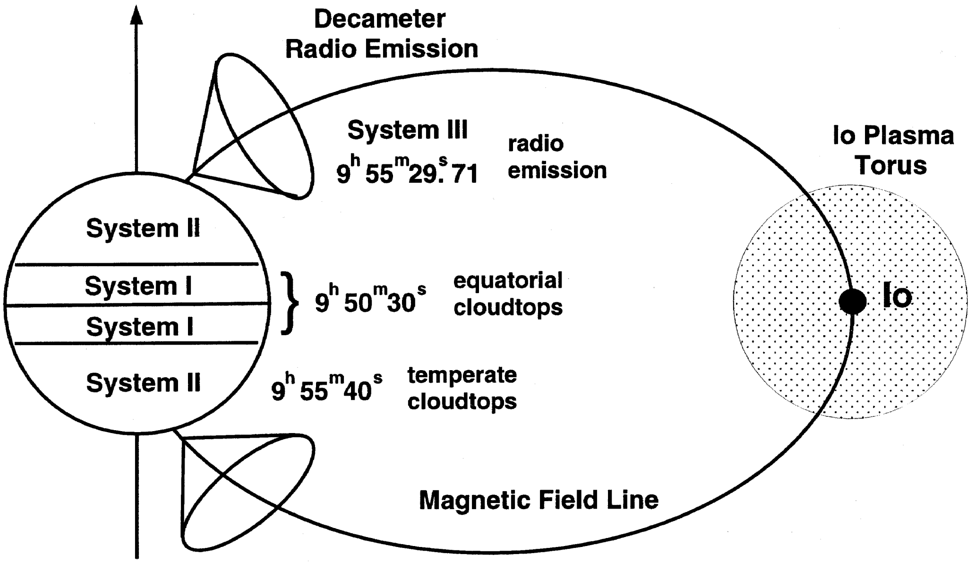

Figure 1: A summary of the Jovian longitude systems and their associated rotation period values.

A corrected rotation period can be calculated from the measurement of the mean rate of this CML drift over a specified time interval. If the initially assumed rotation period is P_o, and it is found that the feature drifts by $\Delta\lambda$ degrees over the time interval Δt, then the corrected period is given by

$$P_c = \frac{360 P_o \Delta t}{(360\Delta t - P_o \Delta\lambda)}. \tag{1}$$

After several early measurements had been made using this method, a drift was found in the results which was later explained as observational effect caused by the changing position of Earth with respect to Jupiter [Gulkis and Carr, 1966]. This observational effect, termed the Jovicentric declination of Earth, or D_E, varies periodically between about $-3°.3$ and $+3°.4$ over a cycle of Jupiter's orbital period of 12 years. This effect is clearly seen in Figure 2 where the longitudinal position of the 18 MHz peak of the probability of occurrence of radio data is plotted versus time. Also plotted are values of D_E as a function of time which are in phase with the occurrence probability curve values. A change in the CML position of the peaks in the histogram will obviously affect a rotation period measurement calculated with Equation (1). If each individual rotation period measurement is made from a pair of histograms from apparitions having mid-dates separated by about 12 years (so that their mean D_E values were nearly the same), the error in the rotation period can be eliminated. This development in the measurement procedure has considerably improved the rotation period measurement precision that can be obtained from histograms of occurrence probability versus CML.

Using improved decameter and synchrotron measurements, Riddle and Warwick [1976] computed the weighted average of the decametric measurements of Duncan [1971], Carr [1972], and Kaiser and Alexander [1972], and the synchrotron radiation determination of Berge [1974] obtaining the value $9^h\ 55^m\ 29^s.71$. Defined as the System III (1965) Jovian rotation period, it was subsequently adopted by the I.A.U.

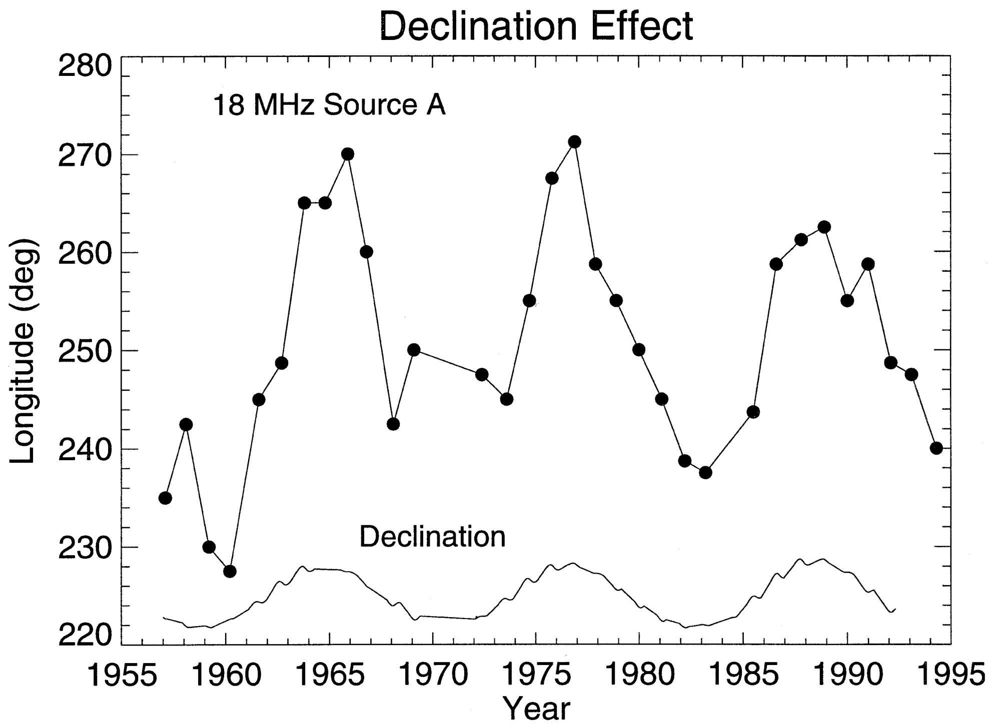

Figure 2: Longitudinal positions of the peak occurrence probabilities for each apparition of source A at 18 MHz are plotted as a function of time. Note the 12-year oscillation in the source location, and also note that the phase of the occurrence probability curve matches that of the D_E curve plotted below for reference.

2 Measurement Procedure

Our rotation period measurement is made from data that are derived from chart recordings of nightly observations of Jupiter's decametric radiation at two or three of the frequencies, 18, 20, and 22 MHz during every apparition from 1957 to 1994. A summary of all the observations used in this study is given in Table 1. Data obtained after 1977 have been recently reduced and have never been published or used for rotation period determinations.

The antenna for each frequency channel was usually a 5-element tracking yagi attached to a receiver with a 6 kHz bandwidth. The receiver inputs, along with appropriate time marks, were pen-recorded on analog strip charts having a recording time constant of about one second.

The data were separated into subsets obtained at one observatory at a single frequency during pairs of apparitions having mid-dates that were approximately 24 or 12 years apart. This is the first time that pairs of observing apparitions separated by 24 years are available. The average values of D_E during the two apparitions of each such pair were thus nearly the same. The Florida and Chile data obtained during the same apparitions were analyzed separately. There were a total of 31 of the 24-year pairs and 16 of the 12-year pairs. There was no case in which the Florida data from one apparition were used in more than one of these pairs, nor was there such a case for the Chile data. Each such single-observatory, single-frequency, constant-D_E apparition pair yielded one rotation period

Table 1: Summary of Observations

Florida Data: 1957 - 1994			Chile Data: 1960 - 64, 1972 - 76		
Frequency (MHz)	Observations (hours)	Activity (hours)	Frequency (MHz)	Observations (hours)	Activity (hours)
18	31,001	2,384	18	∼10,500	1,131
20	28,788	1,533			
22	34,106	1,487	22	∼10,500	610
Total	93,895	5,404	Total	∼21,000	1,741

measurement. We used the cross-correlation method developed by May et al. [1979] in measuring the CML drift in the occurrence probability histogram between the first and second apparitions of each pair. This method is illustrated in Figure 3 (from Higgins et al. [1996]). The two histograms obtained at the same observatory and the same frequency during two apparitions separated by about 24 years are shown in panels (a) and (b). The cross correlation function (shown in panel (c)) is the plot of cross correlation coefficients versus the CML shift of the second histogram relative to the first one. The CML shift for maximum correlation, in degrees, is $\Delta\lambda$. The corrected rotation period, P_c, is calculated by means of Equation (1).

The averaging of these initially determined rotation period values was done in two stages. Values obtained from different pairs of apparitions can certainly be considered to be statistically independent. We also considered that values obtained during the same apparition pair but at different observatories to be independent, although they may not be completely so. However, values obtained from more than one frequency channel at one observatory are not completely independent of each other. Although the 2 MHz separation between adjacent frequency channels is sufficiently large that the individual bursts occurring during a noise storm on one channel do not necessarily appear simultaneously on the other, there is considerable correlation between the general times of noise storm occurrence on the two frequency channels. We therefore compute a single weighted average period from the one, two, or three frequency channels that were operated simultaneously at one observatory during each of the selected apparition pairs. The weighting factor that was used is the product of two parts. The first part, which depends on the *quantity* of the Jupiter emission data that was available, is the square root of the geometric mean of the respective Jovian activity times observed during the two apparitions of the selected pair at the given frequency. The second part, which is an indication of the *quality* of the data, is the maximum value of the cross correlation coefficient that was obtained (i.e., the value corresponding to the CML shift $\Delta\lambda$).

This first stage of averaging yields a list of statistically independent rotation period measurements, one for each of the selected apparition pairs (separately for the Florida and Chile observatories). Associated with each of these initial averages is a resultant weighting factor derived from the one, two, or three individual frequencies used in computing it. This list consists of 13 rotation period values each of which is the average over 24 years, and 11 that were averaged over 12 years. The final weighted mean rotation period and the standard deviation of the mean were obtained from this list.

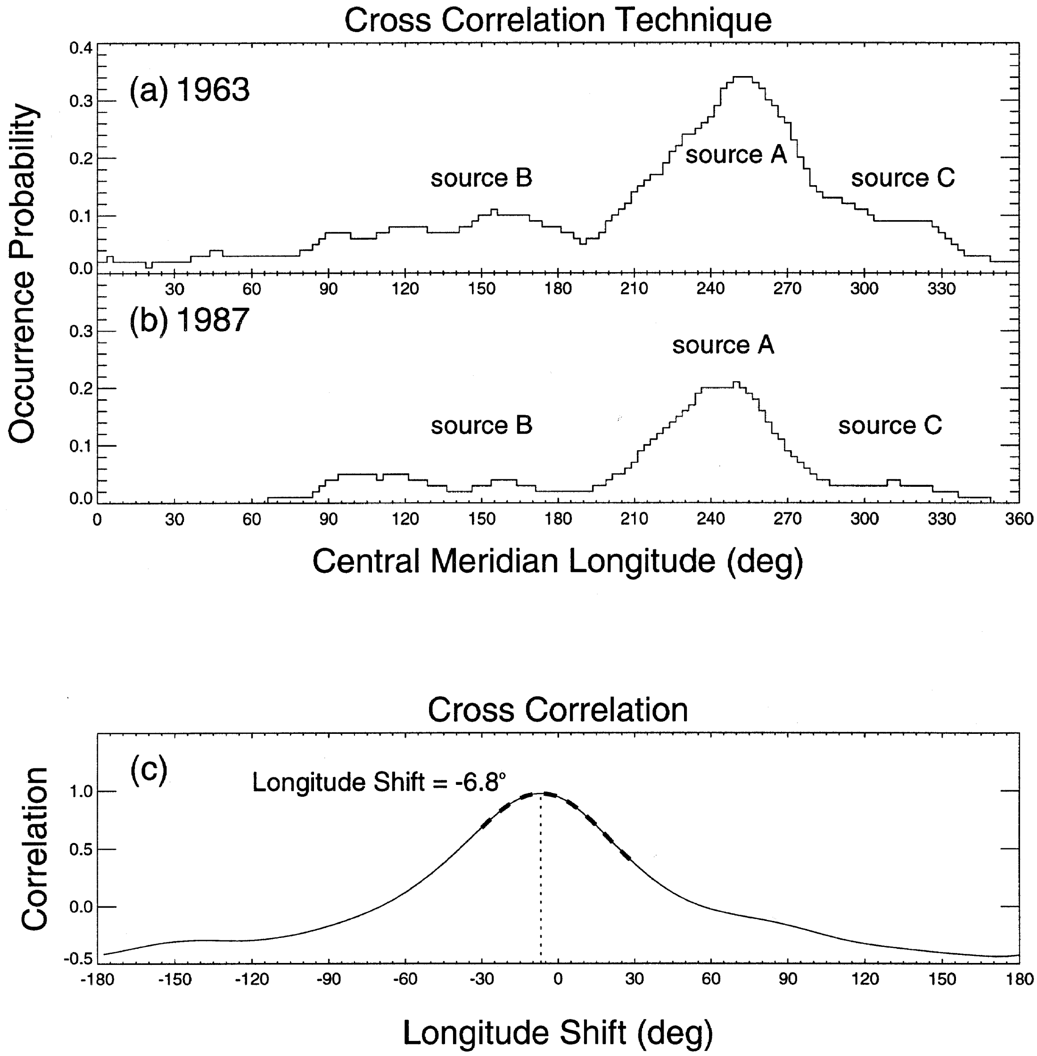

Figure 3: Data used for a single rotation period measurement. Panel (a) is the histogram of occurrence probability versus CML at 22 MHz for the 1963 apparition. The peaks commonly known as sources A, B, and C are labeled. Panel (b) is the same type of histogram for the 1987 apparition. Panel (c) is a smoothed plot of the cross correlation of the two histograms as a function of the shift of the later one with respect to the earlier one. The maximum correlation here is 0.975, occurring at a longitude shift of $-6°.8$ *(from Higgins et al. [1996]).*

3 Results and Discussion

The final value obtained for the weighted mean rotation period is

$$P = 9^h 55^m 29^s.685 \pm 0^s.0034, \tag{2}$$

where $0^s.0034$ is the standard deviation of the mean. We are confident that our standard deviation estimate is realistic. Expressed in seconds, the rotation period becomes

$$P = 35729^s.685 \pm 0^s.0034. \tag{3}$$

The precision of the measurement is thus one part in 10 million.

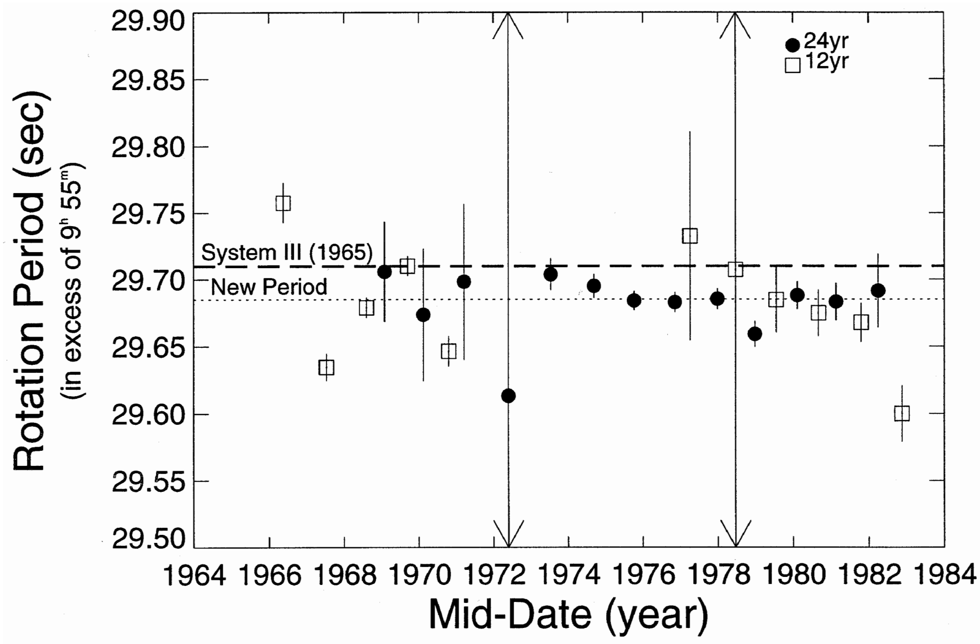

Figure 4: Plot of our 24 independent rotation period measurements as a function of the mid-date of the time interval over which each period was averaged. The black circles represent 24-year averages and the white boxes are 12-year averages. The error bar heights are inversely proportional to their statistical weights. The light dotted line is the weighted mean of the values. The heavy dashed line is the currently accepted System III (1965) period (from Higgins et al. [1996]).

Our individual 24-year and 12-year average rotation period values are plotted as a function of the mid-dates of their averaging intervals in Figure 4 (from Higgins et al. [1996]). System III (1965) and our new period are plotted for reference. The error bar lengths are inversely proportional to the statistical weights. Two of the points have relatively little weight, because of abnormally short observing seasons in combination with low rates of Jovian activity. Their error bars are far off-scale in the plot.

We compare our new rotation period with the currently accepted System III (1965) value. As seen in Figure 4, the System III (1965) value is too high when compared to our 24 independent measurements. A statistical comparison of our weighted distribution and System III (1965) is shown in Figure 5. The dotted histogram represents the normalized weighted frequency distribution of all 24 measurements used in our final calculation. A Gaussian curve is plotted over the histogram with the mean and standard deviation of our new period. Our weighted distribution is obviously not Gaussian and the fraction of data with $\pm 1\sigma$ is only about 35%. This may be due to other factors affecting our data, such as solar influences, Io-Jupiter interactions, or other beaming effects. A reference line for System III (1965) is also included. The difference between the accepted value and our new one is $0^s.025 \pm 0^s.0034$, which is 7.4 times the standard deviation of our value. This is a highly significant difference; it would result in a drift between the two rotation systems of about $0°.2$ per year ($4°.4$ since System III (1965) was adopted in 1976). Our measurement of the Jovian rotation period, which is by a considerable margin the most

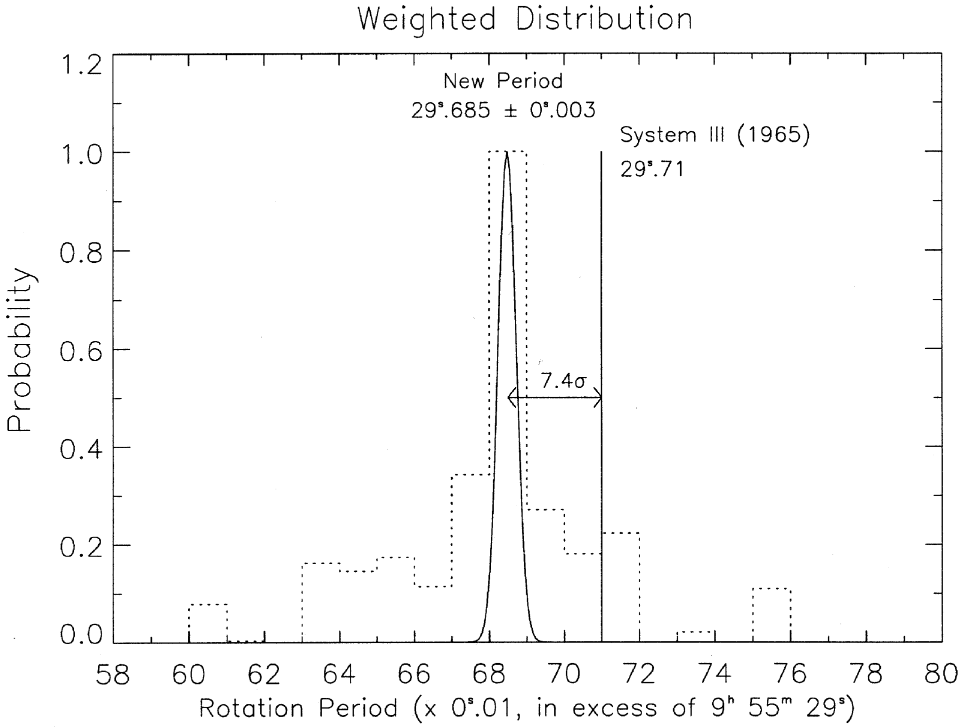

Figure 5: Statistical significance of our weighted distribution as compared to System III (1965). The dotted histogram represents the normalized weighted frequency distribution of all 24 measurements used in our final calculation. A Gaussian curve is plotted over the histogram with the mean and standard deviation of our new period. A reference line for System III (1965) is also included. Our new measurement differs from System III (1965) by 7.4σ which is highly significant.

precise that has yet been made, therefore indicates that the present I.A.U. standard value needs to be decreased.

The new rotation period calculation is a result of combining many years of data which we are now able to analyze with respect to time. Using the 24-year data from Figure 4, we plot the individual rotation period measurements as a function of time in Figure 6. We only use the 24-year data here because of the longer time span of data and the greater confidence we have in those measurements. The relative errors indicated are again inversely proportional to their weights. A weighted least squares fit to the data is also shown on the plot and the slope is -1.74 ms/year. The error in this fit is large (27.1 ms/year) and no conclusion can be drawn about a drift in the rotation period based on these data. From this least squares fit, however, we can conclude that the true rotation period of the Jovian inner magnetosphere is not changing linearly at a rate in excess of 27.1 milliseconds per year.

If a program of monitoring Jupiter's decametric radiation were continued indefinitely, a true change would surely be detected eventually. Such a change would be expected to result from the Jovian equivalent of terrestrial magnetic polar wandering. It is possible, of course, that some unexpected future long-enduring upset in the magnetospheric plasma distribution might alter the characteristic shapes of the histograms of the decametric

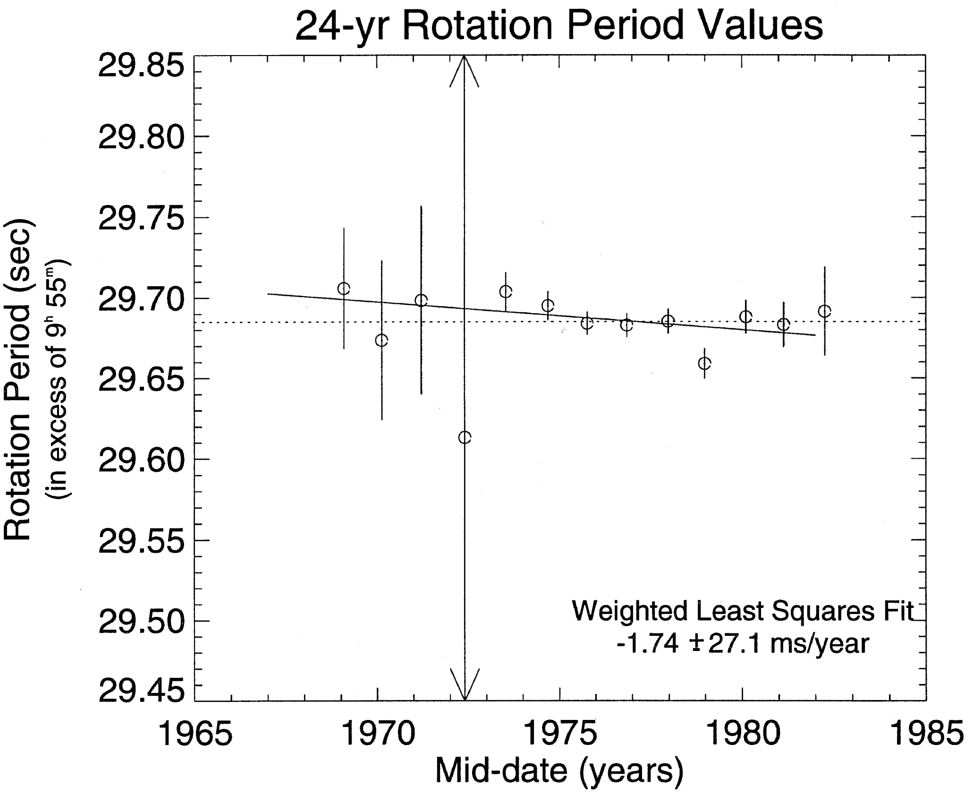

Figure 6: The 24-year rotation periods plotted as a function of time. Error bars are inversely proportional to the weights. The horizontal dashed line is a reference of our new period, and the solid line is a weighted linear least squares fit to the data with the slope and error given.

emission occurrence probability versus CML before the polar wandering effect became apparent. In any event, it is clear that the continued monitoring of Jupiter's decametric radiation from Earth will remain a source of important new information on the magnetosphere and magnetic field of the planet for a long time.

Acknowledgements: This research was conducted with partial support from a long series of grants from the *National Science Foundation*, currently Grant No. AST9406501.