2.11 TIMING OBSERVATIONS OF THE CRAB NEBULA PULSAR AT THE ARECIBO OBSERVATORY

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Abstract. Timing observations of the Crab pulsar were made between 10 May 1969 to 3 July 1970. Arrival times were corrected to the barycentre of the solar system; a further correction was made for the effect of dispersion. The only jump in period occurred in September 1969, although small irregularities in the period occurred at other times. A third order polynomial fitted all the observed data to within ± 0.15 pulse periods.

Since May 1969 timing observations of the Crab Nebula pulsar have been made at the Arecibo Observatory approximately twice per week. Observations are made simultaneously at 2 or more of the frequencies 430, 318, 196.5, 111.5 and 73.8 MHz, with a sampling interval of 32 μsec. For each run of approximately 18 min (32000 pulse periods) the corresponding samples in successive pulse periods are summed. Between 5 and 9 such runs are usually made on one observing day. Topocentric arrival times are found by cross-correlating the summed data with an expected pulse shape which includes the effects of the receiver parameters, and the pulse smearing which is presumed to be caused by interstellar multipath propagation. Further details are given by Rankin *et al.* (1970).

By using Loran C transmissions the observatory time is referenced to the U.T.C. system to better than 10 μsec. Corrections are made for the *periodic* error of a terrestrial clock caused by the non-circular orbit of the earth (Clemence and Szebehely, 1967), and arrival times are referenced to the solar system barycentre using an ephemeris kindly provided by Ash, Shapiro and Smith of the MIT Lincoln Laboratory. A ten day average of the dispersion constant deduced from the same observations (Rankin and Roberts, 1970) is used to extrapolate the 430 MHz barycentric arrival times to infinite radio frequency. Pulse numbers are assigned successively by extrapolating the known previous behaviour of the pulsar. Finally, daily mean arrival times are found from cubic fits of pulse number versus arrival time made to data from several successive observing days. For the interval 10 May 1969 to 3 July 1970 there are 112 such daily mean arrival times.

To examine irregularities in the pulsar behaviour, observations on successive observing days are used to derive a mean pulsar repetition frequency for the intervening days. The pulsar slows down so rapidly that it is necessary to add a linear function of the time to these frequencies before plotting. Figure 1 shows such plots for successive, and partly overlapping, intervals of approximately 100 days. A different multiple of the time was chosen for each section so that the residuals would form approximately symmetric curves.

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The frequency jump in September, 1969 (Boynton *et al.*, 1969; Richards *et al.*, 1969) is clearly seen in the second curve from the bottom. There are no other such obvious frequency jumps. There are, however, times when the pulsar behaviour is irregular and some of these irregularities may be caused by smaller frequency jumps, as for example in the interval between 12 April 1970 and 24 April 1970 (left hand side of the top curve). However the much larger irregularities in the mean frequencies seen in June and July 1970 (right hand side of upper curve) do not appear to indicate permanent frequency jumps.

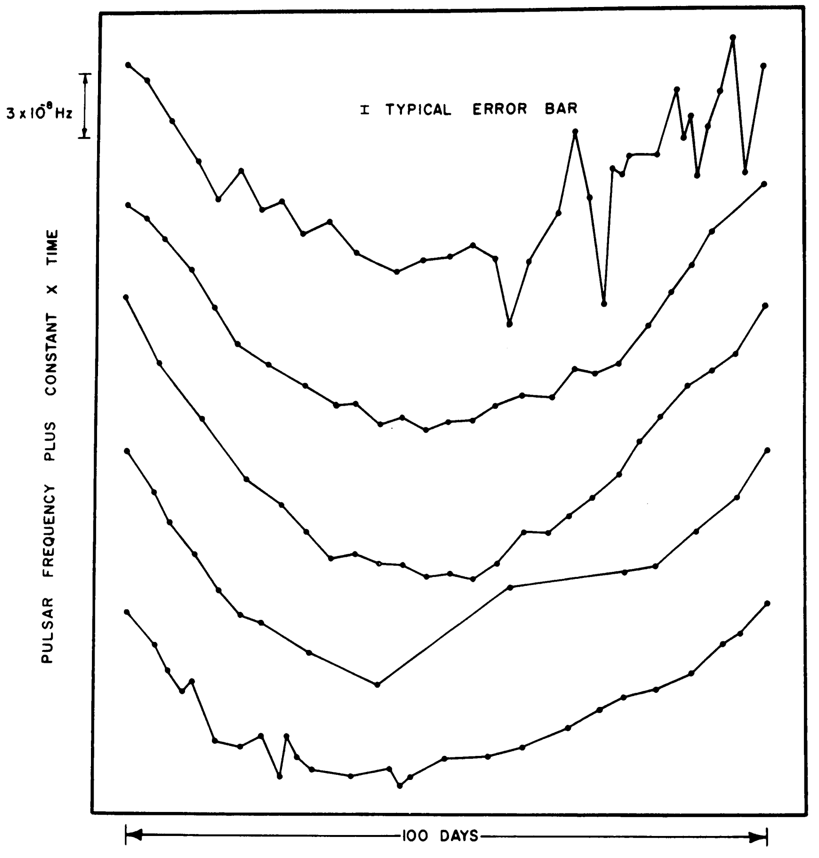

Fig. 1. Mean pulsar repetition frequency deduced from arrival times on two successive observing days, plus a multiple of the mean of the two arrival times plotted as a function of this mean time. The 'typical error bar' corresponds to errors of 20 μsec ($\sim$ twice the rms error) at either end of a 3 day interval. The error increases for more closely spaced observations and decreases for more widely spaced observations. Bottom curve: 1969 May 10–1969 August 10; Multiplier 3.857972×10^{-10} sec^{-2}. Second bottom: 1969 July 30–1969 November 12; Multiplier 3.857096×10^{-10} sec^{-2}. Middle curve: 1969 October 20–1970 January 20; Multiplier 3.856300×10^{-10} sec^{-2}. Second top: 1969 December 30–1970 April 6; Multiplier 3.855456×10^{-10} sec^{-2}. Top curve: 1970 March 25–1970 July 3; Multiplier 3.854558×10^{-10} sec^{-2}.

It was hoped that a polynomial fitted to pulse number versus arrival time would describe the steady rotation and slowing down of the star, and leave any irregularities as residuals to the fit. However it is necessary to use at least a cubic to fit the observations, and the interpretation is not clear. Experiments show that a polynomial fitted to a set of observations is not a reliable means of predicting the future behaviour of the pulsar. Fits to the data prior to the end of September 1969 correspond to solution of

$$\mathrm{d}\nu/\mathrm{d}t = -K\nu^n,$$

with $n \simeq 2$. However after the frequency jump n increased to nearly 3, and then decreased to approximately 2.5. The quasi-sinusoidal residuals evident prior to the jump (Richards *et al.*, 1970) perhaps continued until January 1970 and then disappeared rather suddenly.

If a polynomial fitted to arrival times prior to the September 1969 frequency jump is used to predict the future behaviour of the pulsar, it is found, as expected, that actual arrival times are systematically earlier. By 3 July 1970 the accumulated error is 13 full pulse periods. However, if a cubic is fitted to the whole data span from 10 May 1969 to 3 July 1970, the departures from the fit are never greater than ± 0.15 pulse periods. Hence, it is possible that the stellar rotation changed smoothly with time, approximately as described by this cubic ($n = 2.6$), and that the source moved relative to this rotating frame by up to $\pm 50°$.

This note reports one aspect of a project in which J. M. Rankin of the University of Iowa, C. C. Counselman III of MIT and G. H. Pettengill of Arecibo Observatory are also involved. A fuller report of the results will be made at a later date. The project would not have been possible without the full support of the staff of Arecibo Observatory and the financial support of sponsoring agencies. Arecibo Observatory is operated by Cornell University under contract with the National Science Foundation with partial support from the Advanced Research Projects Agency. The present work is also supported in part by Air Force Office of Scientific Research contract F44620-69-C-0092 and NASA grant NGL 16-001-002.

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Discussion

F. C. Michel: What is n for all 500 days? It seems to me that one must either decide to use

$$\frac{d\nu}{dt} = k(t)\,\nu^{n(t)}$$

which is what one does implicitly when one talks about a 'jump in the period', or use

$$\frac{d\nu}{dt} = k\nu^{n} + \mathit{residuals}\,(t)$$

where k and n are constants that are increasingly better determined as more data becomes available, and the residuals represent the short term drift effects. To compromise and fit to constant k and n for different data runs is an unfortunate mixture of these two approaches.

J. A. Roberts: $n \simeq 2.6$ for the whole time interval.

R. G. Conway: You showed two periods of time when the pulse frequency was 'rough'. Am I right in thinking that they both occurred in June when the Sun and Crab are close?

J. A. Roberts: There is no real correlation between the occurrence of roughness and being near the Sun.

R. Schwarz: Could the 'rough' periods be connected with changes in the dispersion measure?

J. A. Roberts: The effects of dispersion measure changes upon arrival times have been removed.