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Daily Observations of Three Period Jumps of the Vela Pulsar*

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Abstract

Daily observations of the period of the Vela pulsar have been made since 8 October 1981. During this time three period jumps have been observed: in October 1981, August 1982 and July 1985. An empirical model is fitted to the period decay following each of these jumps, and the characteristics of the jumps compared.

Observations of the Vela pulsar have been made at Hobart almost daily since 8 October 1981. During this period three discontinuous jumps or 'glitches' in pulsar period have occurred (McCulloch *et al.* 1981, 1983; Hamilton *et al.* 1982; Klekociuk *et al.* 1985). The observations have been made at 635 MHz using a 14 m diameter antenna which can track the source for 5 hours. A dual channel receiver with FET first stages is used to give two linear polarisations which are summed after detection to give the total intensity. The system noise temperature in each channel is around 100 K. Integrated pulse profiles of 1000 pulses are recorded at intervals of about 2 minutes; these have a signal-to-noise ratio of about 20 : 1, allowing a mean pulse arrival time to be determined with an uncertainty of around 100 μs. All the arrival time data are subsequently reduced to arrival times at the Solar System barycentre. The data presented in this paper have been obtained by combining about a dozen 2 minute integrations to give mean arrival times averaged over about 25 minutes with an uncertainty of around 30 μs.

The results presented are based on data recorded in the two months immediately preceding each glitch and the six weeks immediately following. The observations at Hobart did not commence until three days prior to the first glitch so that pre-glitch data recorded at Tidbinbilla at 2295 MHz have been used for this event, as discussed by McCulloch *et al.* (1983). Pulsar periods around the time of each period jump are plotted in Fig. 1, and show the usual secular increase of about 10·7 ns per day together with an abrupt decrease at the times of the discontinuities. The magnitudes of the three period decreases are about 102, 182 and 143 ns respectively. These are similar in magnitude to four previously recorded jumps (Downs 1981).

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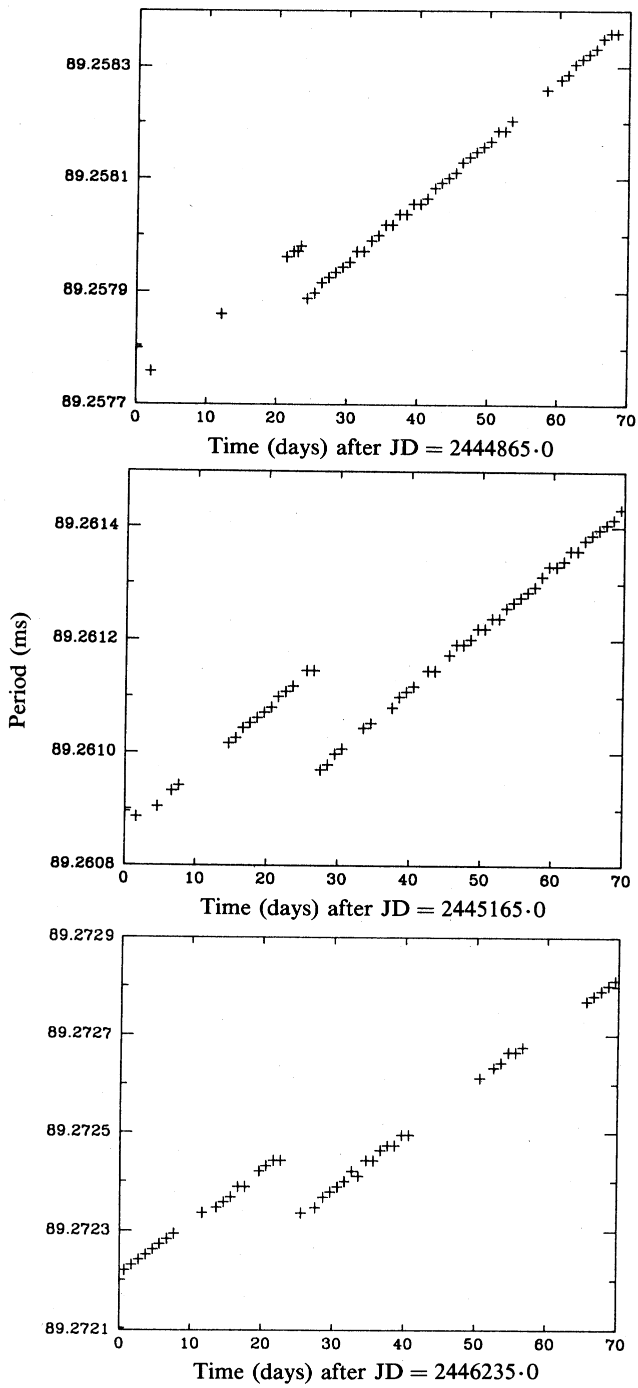

Fig. 1. Plots of the pulsar period determined daily about the time of occurrence of each of the three period jumps.

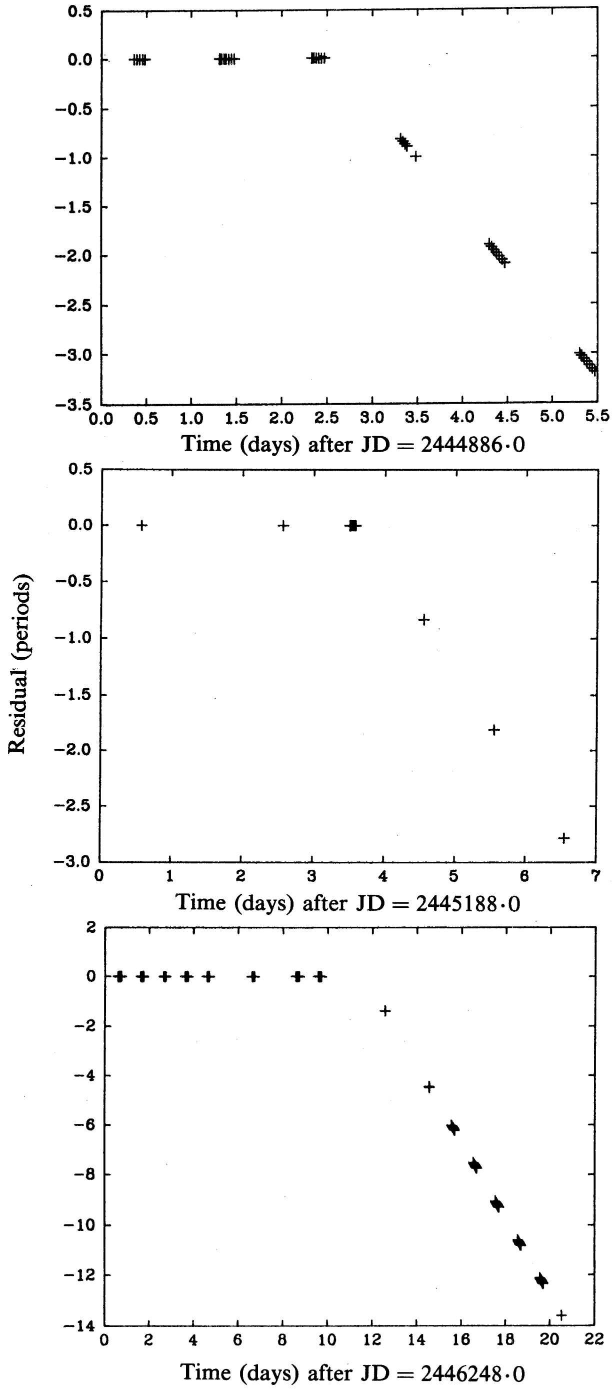

Fig. 2. Phase residuals from the pre-jump cubic fit near the time of occurrence of each of the three period jumps.

The pre-jump arrival time data for each of the glitches are well fitted by a cubic equation, giving the pulse phase at time t as

$$\phi(t) = \phi_0 + \nu(t - T_0) + \tfrac{1}{2}\dot{\nu}(t - T_0)^2 + \tfrac{1}{6}\ddot{\nu}(t - T_0)^3 . \qquad (1)$$

The parameters for these fits are given in Table 1. It should be noted that at the time of the second period jump the magnitude of $\ddot{\nu}$ was well above its normal range, which may be deduced from Downs (1981) to be from 5×10^{-24} to 9×10^{-24} Hz s^{-2}. This indicates that the pulsar was still recovering from the first period jump.

Table 1. Pre-jump parameters fitted by equation (1)
In each case the error is in the last digit quoted

Parameter	1981 glitch	1982 glitch	1985 glitch
ν (Hz)	$11{\cdot}2036049179\pm4$	$11{\cdot}2031556227\pm9$	$11{\cdot}2016866562\pm2$
$\dot{\nu}$ (Hz s^{-1})	$(-1{\cdot}55878\pm2)\times10^{-11}$	$(-1{\cdot}56364\pm6)\times10^{-11}$	$(-1{\cdot}56054\pm3)\times10^{-11}$
$\ddot{\nu}$ (Hz s^{-2})	$(3{\cdot}9\pm0{\cdot}5)\times10^{-22}$	$(24\pm2)\times10^{-22}$	$(11\pm1)\times10^{-22}$
Epoch (JD)	2444795·8399	2445137·7458	2446241·6134

Fig. 2 shows the residuals from these fits for the data from a few days spanning each glitch. In each case the linear departure from the predicted phase indicates the presence of the period jump. If we assume that no phase discontinuity occurred at the time of the jump, its epoch can be calculated from the intersection of the extrapolated straight line sections for the pre-jump and post-jump data shown in the residual–time diagrams of Fig. 2. For the events of 1981 and 1982 unique solutions are obtained, while for the 1985 event five solutions are possible since the post-jump residuals are uncertain by an integral number of periods. The three glitches were found to occur at about 01h 40m U.T. on 11 October 1981, about 15h 30m on 10 August 1982 and between 20h 57m on 11 July and 19h 30m on 13 July 1985. These epochs are listed in Table 2.

Table 2. Jump parameters fitted by equation (2)
Alternative epochs are given for the 1985 glitch. In each case the error is in the last digit quoted

Parameter	1981 glitch	1982 glitch	1985 glitch
$\Delta\nu_c$ (Hz)	$(1{\cdot}0476\pm3)\times10^{-5}$	$(2{\cdot}204\pm8)\times10^{-5}$	$(1{\cdot}508\pm1)\times10^{-5}$
$\Delta\nu_1$ (Hz)	$(9{\cdot}2\pm9)\times10^{-8}$	$(23\pm2)\times10^{-8}$	$(6{\cdot}6\pm9)\times10^{-8}$
τ_1 (days)	$1{\cdot}6\pm0{\cdot}2$	$3{\cdot}2\pm0{\cdot}5$	$6{\cdot}5\pm0{\cdot}5$
$\Delta\nu_2$ (Hz)	$(2{\cdot}260\pm3)\times10^{-6}$	$(0{\cdot}79\pm6)\times10^{-6}$	$(2{\cdot}76\pm1)\times10^{-6}$
τ_2 (days)	233 ± 1	60 ± 9	332 ± 10
Epoch (JD)	$2444888{\cdot}5707\pm2$	$2445192{\cdot}1395\pm9$	$2446257{\cdot}7309\pm8$
			$2446258{\cdot}3724\pm8$
			$2446259{\cdot}0184\pm6$
			$2446259{\cdot}6647\pm5$
			$2446260{\cdot}3116\pm4$

The simple post-jump recovery model of a two component neutron star used by Baym *et al.* (1969), in which part of the frequency jump decays away exponentially, is not adequate to explain the data from any of the period jumps. The departures

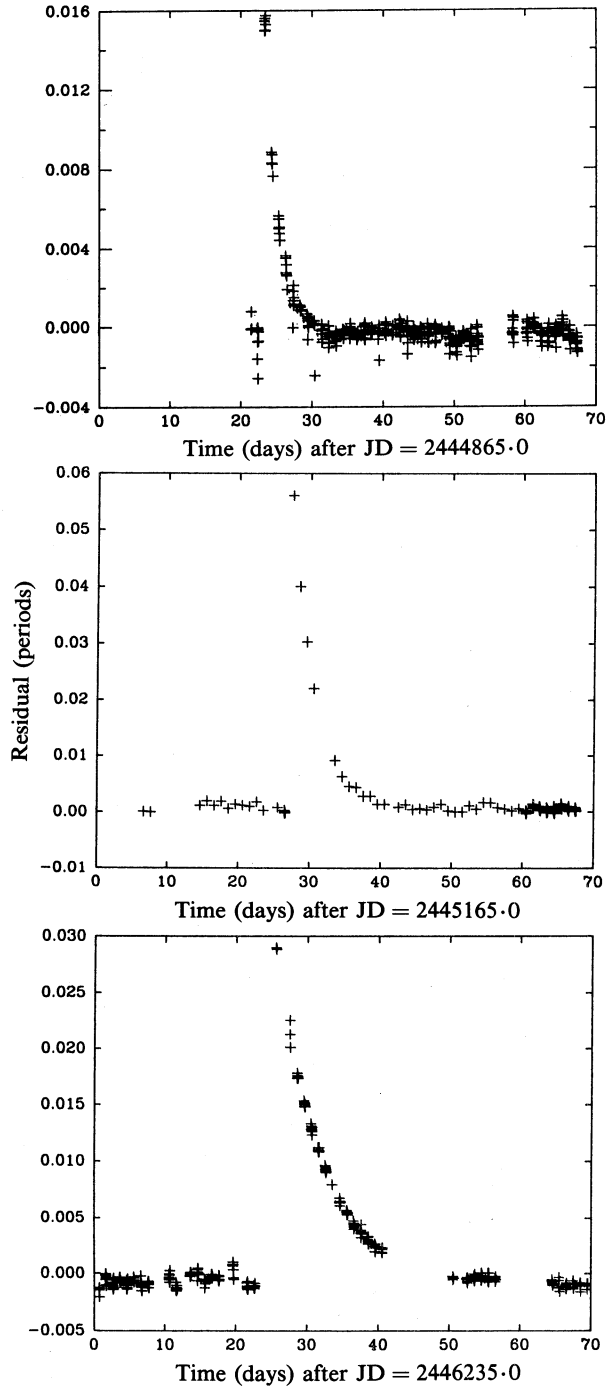

Fig. 3. Phase residuals from the post-jump recovery model used by Baym *et al.* (1981), showing the initial rapid exponential recovery from the glitches.

of the observations from this model are shown in Fig. 3. These residuals are well described by an additional exponential term with a short time constant. Table 2 lists the parameters when the pulse frequency is fitted to the double exponential model used by McCulloch *et al.* (1983):

$$\nu(t) = \nu_{\mathrm{p}}(t) + \Delta\nu_{\mathrm{c}} + \Delta\nu_1 \exp\{-(t - T_j)/\tau_1\} + \Delta\nu_2 \exp\{-(t - T_j)/\tau_2\}\,. \tag{2}$$

The long term recovery of the pulsar is modelled by the parameters $\Delta\nu_2$ and τ_2 which have values consistent with those obtained for previous jumps. Note that data for only 40 days or so after each glitch have been used to solve for the parameters, and that over this time span a cubic would also provide a reasonable fit. The new feature, which was first reported by McCulloch *et al.* for the 1981 glitch, is the initial rapid decay present for all three period jumps. This may indicate the presence of a third component in the neutron star. In each of the three jumps this term represents about 1% of the total frequency jump and decays with a time constant of a few days. The magnitude and time constant does not appear to be related to the overall amplitude of the jump.

We have examined the data from the two linearly polarised channels to see if any change in polarisation accompanies the period jumps. No significant changes have been observed. Since the 1985 glitch we have updated our equipment and we are now recording full polarisation data at 635 and 950 MHz on a daily basis.

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