# THE VELA PULSAR GLITCH OF CHRISTMAS 1988

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**Abstract**

We report the results of detailed observations of the Vela pulsar glitch which occurred on 24 December 1988. The period decrease occurred without warning and took place in much less than 2 minutes. The recovery, which commenced immediately, requires a complex function to model it, including three exponential terms and a damped sinusoid. An offset between data at two observing frequencies commenced at about the glitch epoch and continued for about 40 days; this is consistent with a small increase in dispersion measure or a change in the pulsar magnetic field configuration.

## Introduction

The Vela pulsar is observed to undergo jumps in period every few years. The most recent jump occurred on 1988 December 24, when the period decreased by about two parts in a million (Flanagan 1989, Hamilton *et al.* 1989). Regular period monitoring was in progress at Hobart at the time. The observations were made simultaneously at frequencies of 635 and 950 MHz using a 14-m diameter parabolic antenna with which the source is visible for 18 hours a day. The receiver at each frequency was a full polarimeter, with dual-channel FET amplifiers receiving orthogonal linear polarisations which were combined to give the four Stokes parameters of the signal. The system noise temperature at each frequency was 60 K. A rubidium vapor frequency standard provided a reference for the local oscillators and the station clock. Receiver bandwidths were chosen to limit the pulse broadening due to interstellar dispersion to less than 1% of the pulse period.

Integrated pulse profiles from each polarimeter channel were recorded at intervals of about 2 minutes. The signal-to-noise ratio in each total intensity profile allowed mean pulse arrival times to be determined to an accuracy of about 80 $\mu$s at 635 MHz and 50 $\mu$s at 950 MHz.

## Observations

The data presented in this paper were collected between 1988 October 31 and 1989 March 27. This interval was chosen because microglitches occurred immediately before and after these dates, complicating the analysis. The arrival-time data have been reduced to arrival times at the solar system barycenter using standard techniques. For these calculations the optical position of the Vela pulsar given by Manchester *et al.* (1978) precessed to the epoch of J2000 was used with data on the barycenter from the JPL ephemeris DE200.

The period of the pulsar prior to the glitch is well described in terms of a cubic polynomial giving the pulse phase at time $t$ as

$$\phi(t) = \phi_o + \nu(t-T_o) + \tfrac{1}{2}\dot{\nu}(t-T_o)^2 + \tfrac{1}{6}\ddot{\nu}(t-T_o)^3 \quad (1)$$

where the parameters of this fit are given in table 1 ($\ddot{\nu}$ has a negative sign because the pulsar is in the recovery phase from the microglitch on JD 2447460). The data give a mean value for the dispersion measure to the pulsar of 68.31443 pc cm$^{-3}$.

**Table 1** Pre-jump parameters
Epoch $T_0$ = JD 2447520.5519

| | |
|---|---|
| $\nu$ | $11.19997850771 \pm 2$ Hz |
| $\dot{\nu}$ | $-1.55792 \pm 2 \times 10^{-11}$ Hz s$^{-1}$ |
| $\ddot{\nu}$ | $-3.4 \pm 4 \times 10^{-22}$ Hz s$^{-2}$ |

Figure 1 shows the residuals from the pre-jump fit for data taken on the day of the glitch. Shortly after 19$^{h}$ UT the residuals diverge from the fit indicating a sudden decrease in the pulse period. The lower part of the figure shows an hour of data starting at about 1945 UT; each point is the result of a 2-minute integration. It is clear that the jump in period occurred on a time scale much shorter than 2 minutes and that there was no warning of the impending glitch. The observations are consistent with an instantaneous jump in period.

## Analysis

Data from the interval 23 to 26 December were analyzed by fitting a post-jump recovery function of the form

$$\nu(t) = \nu_p(t) + \Delta\nu_c + \Delta\nu e^{-(t-T_g)/\tau} \quad (2)$$



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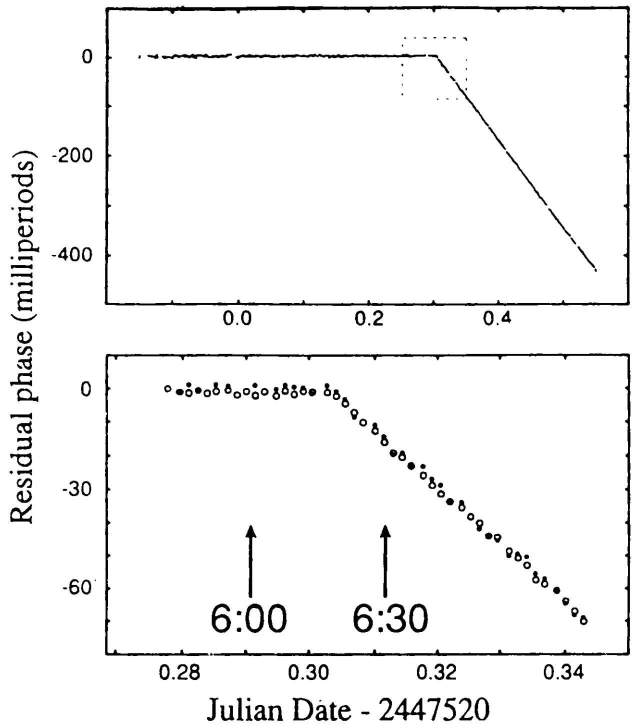


**Figure 1** The residuals from the fit using pre-jump parameters for the day of the glitch. Each point represents a 2-minute integration. The two times marked on the lower plot are local (summer) time at Hobart—on Christmas Day.
*Top:* 635-MHz data for the whole day.
*Bottom:* one hour's data including the glitch.
*Key:* ○ = 950-MHz data, • = 635-MHz data.

where $T_g$ is the jump epoch, $\nu_p(t)$ is the extrapolated pre-jump frequency, $\Delta\nu_c$ is the permanent part of the frequency jump, and $\Delta\nu$ is the component which decays with time constant $\tau$. The epoch, the change in frequency and the change in frequency derivative at the jump given by this fit are listed in table 2.

**Table 2** Parameters of the period jump
Epoch $T_g$ = JD 2447520.30360 ± 8

| | |
|---|---|
| $\Delta\nu$ | $20.218 \pm 9 \times 10^{-6}$ Hz |
| $\Delta\dot{\nu}$ | $-1.2 \pm 1 \times 10^{-12}$ Hz s$^{-1}$ |
| $\Delta\nu/\nu$ | $1.805 \times 10^{-6}$ |
| $\Delta\dot{\nu}/\dot{\nu}$ | $7.7 \times 10^{-2}$ |
| $\tau$ | $1.5 \pm 2$ days |

When data for more than a few days after the glitch are included, this model is inadequate. The longer-term recovery from the jump, examined by analysing data through to 27 March 1989, requires a function similar to that used for earlier glitches (McCulloch *et al.* 1983, McCulloch *et al.* 1987), which were quite well described by:

$$\nu = \nu_p + \Delta\nu_c + \Delta\nu_1 e^{-t/\tau_1} + \Delta\nu_2 e^{-t/\tau_2} \quad (3)$$

where $t$ is the time after the glitch. The parameters obtained by fitting this equation are given in table 3. This model does not fit the data immediately following the glitch; the fit using eq.(2) shows that a much shorter time scale is needed to describe this behavior.

**Table 3** Parameters obtained by fitting eq.(3)

| | |
|---|---|
| $\Delta\nu_c$ | $1.6662 \pm 8 \times 10^{-5}$ Hz |
| $\Delta\nu_1$ | $1.086 \pm 2 \times 10^{-7}$ Hz |
| $\tau_1$ | $4.64 \pm 2$ days |
| $\Delta\nu_2$ | $3.396 \pm 8 \times 10^{-6}$ Hz |
| $\tau_2$ | $351 \pm 1$ days |

Figure 2, top, gives the residuals from the pre-jump fit for 160 days of data at 635 MHz. The center plot shows the residuals after allowing for the constant step in frequency at the glitch ($\Delta\nu_c$, given in table 3). The lower part of the figure was obtained by removing the long-term exponential—that is, the term in $\tau_2$.

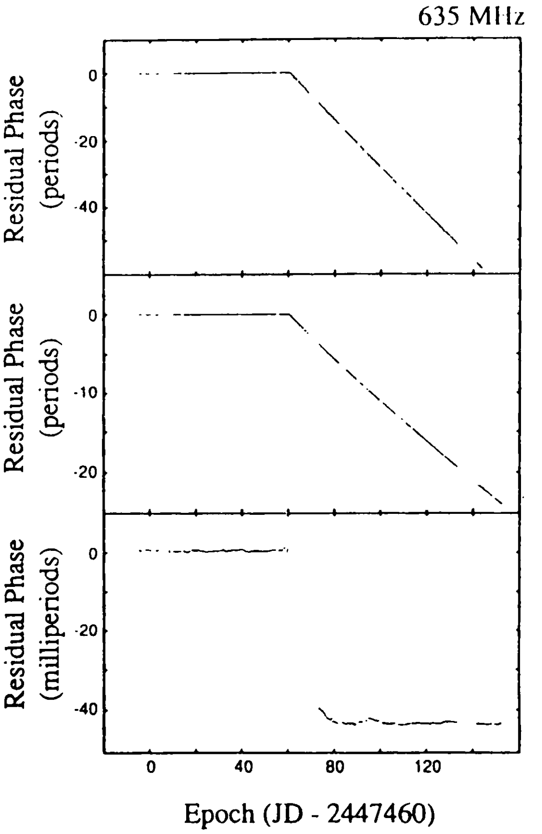


**Figure 2** Residuals after allowing for the different terms of eq.(3)
*Top:* Residuals from the pre-glitch fit.
*Middle:* residuals after allowing for the constant frequency step at the glitch, $\Delta\nu_c$.
*Bottom:* residuals after allowing for $\Delta\nu_c$ and the long-term exponential (note change in vertical scale).

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When the term in $\tau_1$ is also removed we obtain figure 3, which presents the data at both frequen-

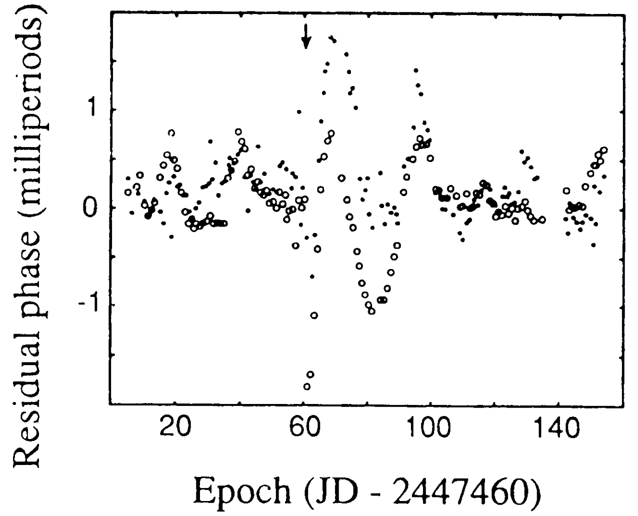


**Figure 3** The residuals from the fit using eq.(3). Each point is the average of one day's data.
*Key:* ∘ = 950 MHz data, · = 635 MHz data.

cies. Damped oscillatory behavior remains, with a maximum amplitude of about 2.5 milliperiods occurring shortly after the jump and with a period of about 25 days. (There is also an offset between the data at the two observing frequencies which starts at about the jump epoch, with the 635-MHz data points consistently lying about one milliperiod later than the corresponding 950-MHz points; this offset disappears after about 40 days.)

In fact, the oscillatory behavior is not well described by a damped sinusoid alone and a further exponential term, with a characteristic time of about a day, is required. The complete description of the recovery requires the following expression:

$$\nu = \nu_p + \Delta\nu_c + \Delta\nu_2 e^{-t/\tau_2} + Ae^{-t/\tau_A} + Be^{-t/\tau_B} + Ce^{-t/\tau_C} \sin\left(\frac{2\pi t}{\tau_S} + \epsilon\right) \quad (4)$$

where the parameters are given in table 4.

**Table 4** Parameters of the complete fit

| | | | |
|---|---|---|---|
| $\Delta\nu_c$ | $1.6662 \times 10^{-5}$ Hz | | |
| $\Delta\nu_2$ | $3.396 \times 10^{-6}$ Hz | $\tau_2$ | 351 days |
| $A$ | $8.7 \times 10^{-8}$ Hz | $\tau_A$ | 5.1 days |
| $B$ | $6.0 \times 10^{-8}$ Hz | $\tau_B$ | 1.0 days |
| $C$ | $2.6 \times 10^{-9}$ Hz | $\tau_C$ | 50 days |
| $\tau_S$ | 29 days | $\epsilon$ | 4.7 rad |

Figure 4 shows plots of this function, excluding the constant and long-period terms, fitted to the data at the two frequencies.

Values of the pulsar frequency derivative $\dot{\nu}$ were obtained by fitting for $\nu$ and $\dot{\nu}$ to sequences of 6

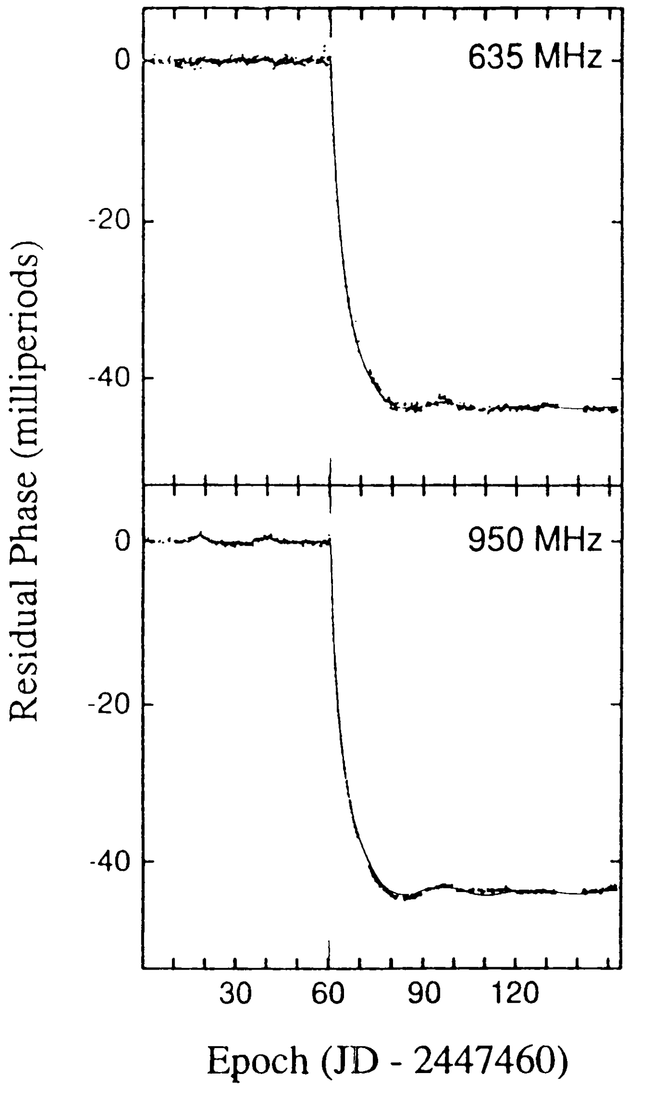


**Figure 4** Residuals after fitting eq.(4), excluding the constant and long-period terms.

days of data which were advanced by one day between successive fits. The values of $\dot{\nu}$ immediately preceeding and following the jump were computed using the parameters given in tables 1 and 2. In order to display the short-term recovery we removed the terms due to $\dot{\nu}$ and $\ddot{\nu}$ (pre-glitch), and the 351-day exponential (post-glitch); the result is shown in figure 5. The short-term components of equation 4 are also plotted on the figure, and it is clear that this equation fits the data well. The data show oscillatory behavior preceding and following the jump, with an amplitude of about $6 \times 10^{-15}$ Hz s$^{-1}$. The amplitude of the corresponding oscillations in phase is 0.1 milliperiods, too small to be seen in figure 3.

## Discussion

The damped sinusoidal oscillation evident in the postjump timing residuals is new feature. This oscillation, with a period of about 25 days, may be

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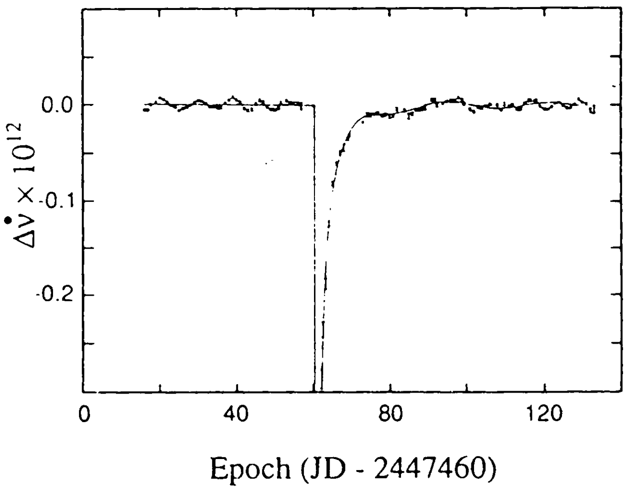


**Figure 5** The variation of frequency derivative $\dot{\nu}$ as a function of time. The terms in $\dot{\nu}$ and $\ddot{\nu}$ (pre-glitch), and the 351-day exponential (post-glitch) have been removed (see text). The error bars are $\pm 2\sigma$.

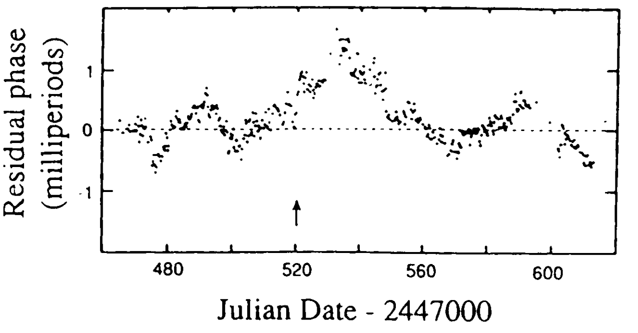


**Figure 6** The difference between arrival times at 950 MHz and 635 MHz. Positive value indicates that 635-MHz data arrived later. The arrow shows the epoch of the glitch.

the result of a lightly damped Tkachenko oscillation, an axial vibration mode of the lattice of vortex lines in the rotating neutron superfluid (Ruderman 1970, Sonin 1987). The width of the equivalent cylindrical region would need to be about 1 km. There is evidence for a shorter period, low-Q oscillation in the timing residuals before the period jump which may have continued for some time afterwards.

Another interesting feature is the time offset, apparent in figure 3, between the data at the two frequencies. Figure 6 shows the phase difference obtained by subtracting the 950-MHz arrival times from the 650-MHz arrival times (positive values indicate that the 635-MHz pulses arrived later). The offset commenced near enough to the jump epoch to suggest a causal relationship. The data are too noisy to allow the exact time of this phenomenon to be determined but suggest that it preceeded the jump. Harwit and Salpeter (1973) have proposed that $\gamma$-ray bursts are the result of cometary impacts on neutron stars. The impact of a comet on a pulsar would cause a local rise in temperature which could trigger a period jump. We would expect the comet to lose a significant fraction of its mass as it approached the pulsar; much of the mass lost would be ionized and could increase the dispersion measure, leading to a time offset between data at different frequencies. The required increase in column density is about $0.016\,\mathrm{pc\,cm^{-3}}$, which represents a total mass of about $10^9$ kg if the material is spread in a spherical layer at the light cylinder radius.

An alternative explanation is that the observed time offset reflects a change in the alignment of the pulsar magnetic field at the epoch of the jump. Such a change may be confined to regions of the magnetic field close to the surface of the pulsar and involve high-order multipole components. Kuzmin *et al.* (1986) have observed similar non-dispersive phase shifts in the high frequency profiles of a number of pulsars, which they interpret in terms of magnetic field restructuring.

Finally, we note that this may be coincidental. The dispersion measure of the Vela pulsar is known to be changing systematically on a time scale of years (Hamilton, Hall, and Costa 1985); the behavior on a shorter time scale should also be investigated.

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