PSR B0826-34: SOMETIMES A ROTATING RADIO TRANSIENT

A. Esamdin1, D. Abdurixit2, R. N. Manchester3, and H. B. Niu1

1 Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi 830011, China; aliyi@xao.ac.cn
2 Department of Physics, Xinjiang University, Urumqi 830046, China
3 CSIRO Astronomy and Space Science, P.O. Box 76, Epping NSW 1710, Australia

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ABSTRACT

We report on the detection of sporadic, strong single pulses coexisting with a periodic weak emission in the duration of weak mode of PSR B0826-34. The intensities and durations of these pulses are comparable with those of the subpulses in the strong mode, and these pulses are distributed within the phase ranges of the main-pulse and interpulse of the strong-mode average profile. These results suggest that there is very possibly sporadic, very short timescale turn-on of strong-mode emission during the weak-mode state of the pulsar. The emission features of the bursts of strong pulses of PSR B0826-34 during its weak-mode state are similar to those of the rotating radio transients (RRATs). PSR B0826-34 is the second known pulsar, which oscillates between pulsar-like and RRAT-like modes.

Key words: pulsars: general – pulsars: individual (PSR B0826-34) – stars: neutron

1. INTRODUCTION

PSR B0826-34 is a relatively old pulsar with a characteristic age of \(3 \times 10^7\) yr (Manchester et al. 1978). An early study of this pulsar at 408 MHz by Durdin et al. (1979) showed that the pulsar exhibits nulls for 70% of the time. Biggs et al. (1985) confirmed the large null fraction, and showed that the emission of the pulsar at 645 MHz extends throughout the pulse period \((P = 1.848\text{ s})\) during its radiation state. They found bands of drifting subpulses with a wide variation of drift rate, including reversal of drift direction. Further investigation by Esamdin et al. (2005) at 1374 MHz detected a weak emission profile during the long null states of the pulsar, and they argued that the null state was a weak-emission mode rather than being a null. However, Bhattacharyya et al. (2008) reported non-detection of emission in a long null state of this pulsar by using the GMRT at 157, 303, 325, 610, and 1060 MHz. Recent Parkes observations of the pulsar at 685 and 3094 MHz confirm the existence of the weak mode emission (Serylak2011). van Leeuwen & Timokhin (2012) also argue the presence of the weak mode of the pulsar, and suggest that the weak mode is a magnetospheric state that is different from the strong mode.

We study the weak mode emission of PSR B0826-34 on an individual-pulse basis by reanalyzing the data used by Esamdin et al. (2005). In this Letter, we report on the detection of the sporadic strong pulses during the weak mode of the pulsar. The detection of single pulses and their properties are described in Section 2. In Section 3, an analysis of periodicity of the weak mode emission is presented. The results are discussed in Section 4, and the conclusions are given in Section 5.

2. SPORADIC STRONG PULSES DETECTED IN THE WEAK-MODE STATE

The data we analyzed were obtained on 2002 September 10 using the 64 m Parkes radio telescope. The central beam of the multibeam receiver was used at a central observing frequency of 1374 MHz with a 96 x 3 MHz analog filter bank (Manchester et al. 2001). The data, lasting 359 minutes, were sampled at 2 ms intervals.

Figure 1 presents the time series of the data which comprises 11,663 individual pulses. The emission in Figure 1 exhibits a block of bursts of continuous strong pulses preceded and followed by long periods of the weak-mode emission which we describe as the weak-mode state hereafter. As shown in Figure 1, the block of bright pulses is present from 32 to 213 minutes (5866 rotations). This block of strong emission is interrupted by 82 short sequences of weak-mode pulses, which last from few to tens of the pulse periods. The weak-mode state, from 0 to 32 minutes and from 213 to 359 minutes in Figure 1, includes 5797 pulse periods in total. In this work, the two durations of weak-mode state are investigated.

The outstanding feature of the two weak-mode blocks in Figure 1 is the existence of rare, short-duration, strong pulses. The inner box in Figure 1 presents 20 minutes of weak-mode data, showing more clearly the rare single pulses. In 178 minutes of weak-mode state, 153 strong pulses with signal-to-noise ratios \((S/N)\) above the 5σ threshold are detected. The \(S/N\) is taken to be the ratio of the peak amplitude in a given pulse period divided by the rms scatter of the points in the same period. The detection rate of the strong pulses is about 51.4 per hr.

Figure 2 shows the average profiles obtained by folding 4500 successive individual pulses in the strong emission block (middle panel) and in the long weak-mode state (bottom panel). A point of minimum intensity throughout the strong-mode profile is defined as both the zero of longitude and the zero of intensity. The pulse profile of the strong mode in the middle panel of Figure 2 basically spans 360° in longitude, implying that this pulsar is most probably an almost-aligned rotator (Esamdin et al. 2005; Bhattacharyya et al. 2008). The strong-mode profile of the pulsar shows two components, i.e., main-pulse (MP) and interpulse (IP; Esamdin et al. 2005; Bhattacharyya et al. 2008). The phases of the two peaks of the weak-mode profile in the bottom panel are coincident with those of the leading and trailing edges of the MP. As shown in the upper panel of Figure 2, the 153 strong pulses are mainly distributed around the phases of 120°, 210°, and 323°, which are coincident with the peak phase of the IP and the phases of the leading and trailing edges of the MP. Most of them are within the longitude ranges of the MP and IP of the strong-mode profile.
Figure 1. Pulse time series for PSR B0826−34. A block of continuous bursts of strong pulses is preceded and followed by long periods of weak-mode emission. A total of 153 strong pulses is detected in the weak-mode states. A section of 20 minutes of weak-mode state is presented in the inner box to show more clearly the sporadic bursts of the strong pulses. The negative-going features associated with strong pulses result from instrumental saturation and are not real. The units of intensity are arbitrary.

Figure 2. Phase-S/N distribution of the 153 detected strong pulses (top panel) compared with the average profiles of the strong (middle panel) and weak mode (bottom panel). Each mean profile was obtained by folding 4500 successive individual pulses. The 153 strong pulses are mostly within the longitude ranges of the MP and IP of the strong-mode profile, and they are mainly distributed around the phases of 120°, 210°, and 323° (top panel).

Esamdin et al. (2005) showed that up to 13 bands of drifting subpulses are detected across a given pulse at 1374 MHz with as many as nine subpulses clearly seen in individual pulses. While most strong pulses occurring during the weak-mode state are isolated, two pulses were detected in each of the 18 individual pulses and three in each of the four individual pulses. Four pairs of pulses were detected in successive periods but for the remainder, pulse separations ranged up to about 380 s.

Figure 3 compares the peak flux intensities and the full width at half maximum (FWHM; W_{50} hereafter) of the strong pulses detected during the weak-mode state with those of subpulses in the bright emission block. The distributions of peak flux intensity and W_{50} of these pulses are essentially identical with those of the subpulses in the bright emission block.

3. PERIODICITY OF THE WEAK-MODE EMISSION

Esamdin et al. (2005) detected the weak-mode average profile by folding the individual pulses in the long “null” state of PSR B0826−34, and noted that the intensity of the average profile of the weak mode is only about 2% of that of the strong mode. However, the identity of the emission which contributes to form the shape of the average profile of the weak mode is not clear. Although the periodicity of the pulsar is hardly detected through them, the possibility of these strong pulses forming the shape of the average profile of the weak mode should be checked.

The periodicity of the weak-mode emission is investigated using the fast Fourier transformation (FFT). Figure 4 compares the FFT results obtained from the strong-mode and weak-mode time series. For the strong-mode block, the rotation frequency of the pulsar (0.540892 Hz) and its four successive harmonics (1.081785, 1.622677, 2.16349, and 2.7043 Hz) are clearly shown in the upper panel of Figure 4. The feature of bands of drifting subpulses are also seen in this spectrum. The rotation frequency and its second, third, and fifth harmonics (indicated by arrows in middle and bottom panels of Figure 4) are also detected with much lower spectrum amplitudes in the weak-mode data. The other peaks shown in the spectra in the middle and bottom panels are caused by instrumental interference. The amplitude of the rotation frequency in the weak mode is only about 2.3% of that in the strong mode. Although the emission is very weak, the periodic character of the weak-mode emission is obvious.

In the bottom panel of Figure 4, we show the FFT of the same weak-mode data section but with the strong individual pulses set to zero amplitude. The rotation frequency and its second, third and fifth harmonics are still seen in the spectrum. The amplitude of the fundamental frequency is only reduced by 5% compared to that of middle panel, indicating that a large part of the energy of the weak-mode average profile comes from
Figure 3. Histograms of relative intensity (panel (a1)) and $W_{50}$ (panel (b1)) of the 153 strong pulses detected in the long weak-mode durations comparing with those of 1540 subpulses in the bright emission block (panels (a2) and (b2)), respectively.

Figure 4. Spectra of the strong-mode (top panel) and the weak-mode emission (middle panel) of PSR B0826$-34$. Each spectrum is obtained by performing FFT to a data section of 106 minute duration. The rotation frequency of the pulsar (0.540892 Hz) and its four successive harmonics are shown in top panel. In the weak-mode state, the rotation frequency and its second, third, and fifth harmonics are detected and indicated by arrows. The spectrum of the same weak-mode data with the strong pulses removed is presented in the bottom panel.

4. DISCUSSION

Pulsar nulling have been detected in about 100 pulsars (Backer 1970; Hesse & Wielebinski 1974; Ritchings 1976; Biggs 1992; Vivekanand 1995; Wang et al. 2007; Gajjar et al. 2012). The nulls of some pulsars are very short (just a few periods), while others are only switched on for a few percent of the time (Wang et al. 2007). The weak-mode emission of PSR B0826$-34$ is so weak that it has long been considered a null (Durdin et al. 1979; Biggs et al. 1985). However, the detection of the weak-mode profile, and especially the periodic weak emission during the weak-mode of this pulsar, implies that there is not an absolute ceasing of radio emission and supports the suggestion that nulling is a type of mode changing (Wang et al. 2007).

The non-detection of the weak-mode profile of the pulsar in GMRT data at six frequencies (Bhattacharyya et al. 2008) indicates that the periodic emission is indeed very weak. The minimum detectable flux density ($5\sigma$) for our observation at 1374 MHz is about 0.6 mJy (the details for the calculation presented by Manchester et al. 2001), which is much lower than the non-detection limit of 15 mJy of GMRT at 1060 MHz noted by Bhattacharyya et al. (2008). However, we expect that a single-pulse search on GMRT data would reveal the strong pulses in the weak-mode state.

The intensities and widths of these strong pulses are comparable with those of the subpulses in the strong mode, and their phases are within the phase ranges of the MP and IP of strong-mode profile. These may indicate that the underlying radiation mechanisms of the strong pulses in the weak-mode state and the strong-mode state are most possibly identical, i.e., that there is very short timescale ($<1$ period) turn-on of strong-mode emission of the pulsar during the weak-mode state.

The behavior of the sporadic bursts of strong pulses during the weak-mode state of PSR B0826$-34$ seems similar to that of the rotating radio transients (RRATs). RRATs are characterized by isolated strong radio pulses, typically from 2 to 30 ms duration (McLaughlin et al. 2006). A typical RRAT does not show detectable regular emission, causing the Fourier-based searches to fail in detecting a periodic signal. However, the timing analysis of the sporadic pulses has confirmed that RRATs are indeed periodic rotators, with the periods ranging from 0.4 to 7 s (McLaughlin et al. 2006, 2009; Keane et al. 2011). More than 50 RRATs have been found so far (McLaughlin et al. 2006; Deneva et al. 2009; Keane et al. 2010; Burke-Spolaor & Bailes 2010; Keane et al. 2011; Burke-Spolaor et al. 2011). Several pairs of pulses have been found from RRAT J1819$-1458$ (Esamdin et al. 2008; Hu et al. 2011). Underlying periodic weak emission has been detected in some RRATs (Burke-Spolaor et al. 2011; Keane et al. 2011). Recent investigations show that RRATs likely represent a combination of neutron star source populations rather than a single class

periodic weak emission. Although the strong pulses detected in the weak-mode state are very strong relative to the weak-mode emission, they are short and rare and have only a minor effect on the shape of weak-mode average profile. The essential character of the emission during the weak-mode state of the pulsar is the coexistence of the periodic weak emission and the sporadic strong pulses.
PSR B0826−34 switches between a strong mode and a weak mode with a typical timescales of hours. By analyzing a Parkes data set obtained at 1374 MHz, we show for the first time that sporadic strong pulses coexist with periodic weak emission during the weak-mode state of the pulsar. A total of 153 strong pulses, with S/N ≥ 5, are detected during 178 minutes of the weak-mode state with a few occurring within a pulse period. The detection rate of the strong pulses is about 51.4 per hr. These pulses have an average pulse width, W_{50}, of 24.0 ms. The intensities and widths of these strong pulses are comparable with those of the subpulses in the strong mode, and their phases are mainly distributed within the MP and IP of the strong-mode average profile. The results indicate that these pulses are most possibly strong-mode pulses with a very short on-timescale.

PSR B0826−34 in its weak-mode state has properties identical to a typical RRAT. This pulsar is the second pulsar found, which oscillates between a pulsar phase and an RRAT phase. PSR B0826−34 is a relatively old pulsar which may be transitioning from a bright phase to a weak phase. The almost-aligned rotator, the switching between the strong and weak mode, the remarkable drifting behavior in the strong-mode, and the periodic weak emission and strong sporadic pulses during the weak-mode state make PSR B0826−34 an amazing object illustrating many facets of the radio radiation mechanism of neutron stars. Further investigations of this pulsar are likely to be fruitful.

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