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Monitoring of Pulse Intensity and Mode Changing for PSR B0329+54

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Abstract We monitored PSR B0329+54 for four months using the Nanshan 25-m radio telescope at 1540 MHz. The observations reveal three mode changing events, that lasted for 37, 12 and 17 min respectively. The integrated flux densities for the different observations differ greatly from their average value. The modulation indices of individual observations vary in a wide range as well, indicating that the intrinsic flux density is largely modulated by the scintillation effect.

Key words: ISM: general — pulsars: general — pulsars: individual (B0329+54)— stars: neutron

1 INTRODUCTION

Single pulse observations of radio pulsars are very important in understanding the size, shape, and location of the observed emission from radio pulsars. After nearly four decades of pulsar studies, much still remains to be understood about the radio pulsar emission processes (see, for example, Rankin 1983, 1986; Gil 1991; Kramer et al. 2003). Many single frequency and simultaneous multi-frequency flux density measurements have been done since the early days of pulsar research. PSR B0329+54 is particularly a good candidate for pulse flux density studies as it is one of the strongest pulsars in the sky and, as well, exhibits many interesting emission features that are not yet well understood. This pulsar is known for mode changing; the pulse profile switches between two different modes – the normal and the abnormal modes (Lyne 1971). Rankin (1986) shows that this pulsar exhibits three abnormal modes at 1.4 GHz. In this paper we present our observations of the mode changes for PSR B0329+54 as well as an analysis of the flux density variations and modulation from both interstellar scintillation (ISS) and intrinsic emission processes.

2 OBSERVATIONS

Observations were made from 2005 December to 2006 March using the Nanshan 25-m radio telescope operated by the Urumqi Observatory. The telescope has Cassegrain optics and uses a dual-channel cryogenic system that receives orthogonal linear polarizations. The central observing frequency is 1540 MHz with a total bandwidth of 320 MHz. The polarizations are split by an ortho-mode transducer (OMT) at the end of the feed, amplified and then down-converted to an intermediate frequency (IF) in the range 80–400 MHz using a local oscillator (LO) at 1300 MHz. Details of the receiver and the data acquisition system is given by Wang et al. (2001). The receiver noise temperature is about 10 K and the system temperature is approximately 23 K, corresponding to a system equivalent flux density of 261 Jy. De-dispersion is provided by a 128×2.5 MHz filterbank/digitizer system. Our typical sample rate is 0.5 ms.

The pulses were calibrated using a diode noise source, which was referenced to well-known stable radio sources such as 3C295 and 3C123 (Ott et al. 1994). The calibrations were carefully done and we consider the flux density results reliable.

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3 DATA ANALYSIS & RESULTS

Altogether 11 observations were made in four months, each lasting for 1, 2 or 2.5 hr. Three mode changing events were detected. Figure 1 shows the mean pulse profiles of the normal and abnormal modes at the mode changing epochs. In both modes, three emission components are prominent; the main pulse in the middle and two outriders, the leading and trailing components, beside it. Our observations indicate that mode changing generally occurs suddenly, with a time scale of less than one pulse.

The observation on MJD 53825 has two mode-changing events. Figure 2 is a plot of the flux density in grey scale style and the corresponding pulse profiles which were integrated over 100 pulses. This figure shows that mode changing affects the two linear polarizations differently, showing that the two modes have different polarization properties and their intensities are different; polarization A being generally stronger than polarization B. For this observation the durations of the two abnormal mode events were 12 min and 17 min, respectively. Their intensities reversed at abnormal mode with the leading component 1.4 times stronger than the trailing components (shown in Figure 3). This was also noticed by earlier observers (see, for example, Lyne 1971).

It has been argued that flux density variations are dominated by refractive scintillation and that the intrinsic pulsar radio luminosities are relatively stable (Kaspi & Stinebring 1992). At our observing frequency, PSR B0329+54 should be in the strong ISS regime (Malofeev et al. 1996). Its diffractive scintillation time scale ($\Delta t_{\rm DISS}$) is $\sim$17 min, de-correlation bandwidth ($\Delta\nu_{\rm DISS}$) $\sim$14 MHz and refractive scintillation time scale ($\Delta t_{\rm RISS}$) $\sim$2.5 d (Wang et al. 2005). We adopt the procedure of Kramer et al. (2003) to correct for the short term variation due to ISS and obtain the intrinsic pulse flux density value. The mean flux densities of

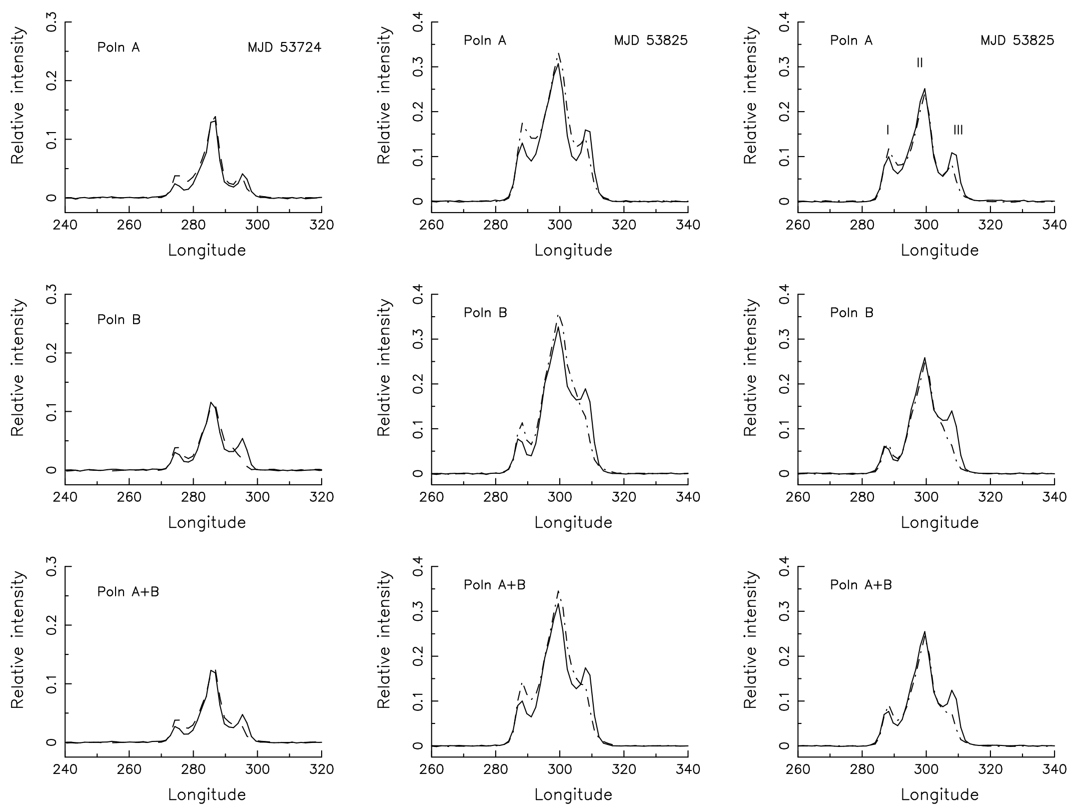

Fig. 1 Average pulse profiles of PSR B0329+54 at polarization A and B, and a combination of the two (A+B). The normal and abnormal modes represent as solid line and dashed line respectively. The leading component is defined as component I in this paper while the trailing one is component III.

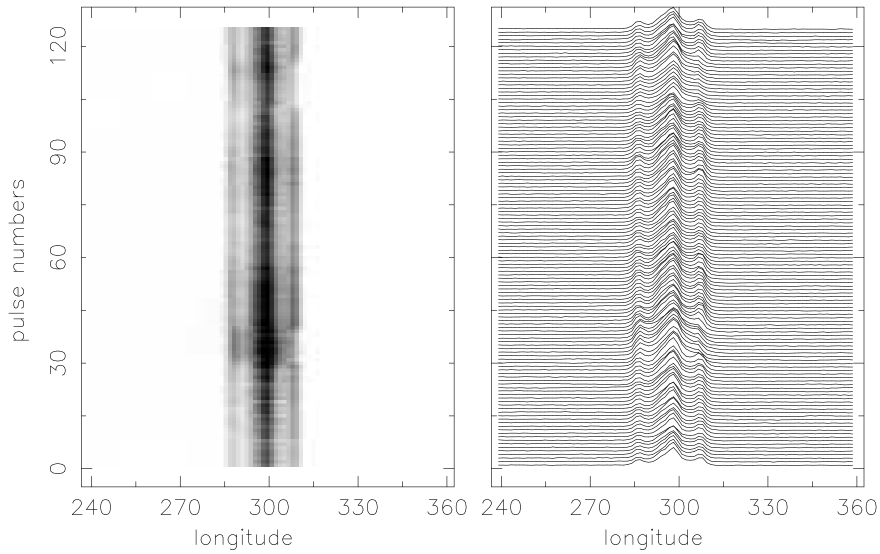

Fig. 2 Gray scale plots of the mode changing events on MJD 53825, along with the corresponding mean pulse profiles.

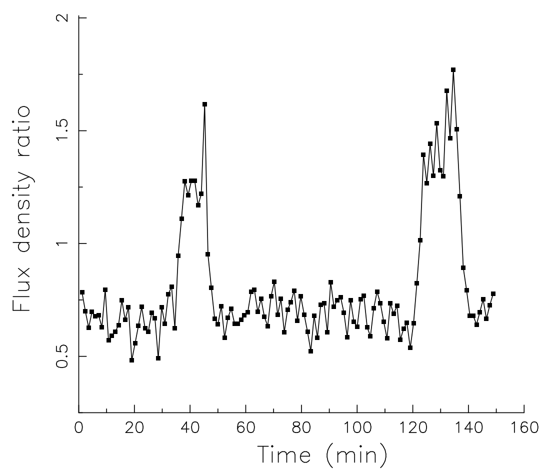

Fig. 3 The flux intensity ratio of components I and III for the observations on MJD 53825.

the 11 observations are presented in Figure 4(a), which shows a time variation of the flux density. The average flux density is 180 mJy which is in good agreement with our earlier work (Wang et al. 2005). However the individual flux densities vary widely from 76 to 281 mJy.

We also investigated the flux density variation for each observation. The modulation index of flux density variation, m is given by

$$m^2 = \frac{\langle (S - \langle S \rangle)^2 \rangle}{\langle S \rangle^2}, \tag{1}$$

where S is the measured flux density and $\langle S \rangle$ is its mean value. The modulation to flux density could be due to interstellar scintillation and intrinsic variation. To obtain an estimation for intrinsic flux variation, we integrated the pulses with 200 periods ($\sim$140 s), this time scale is longer than the intrinsic pulse-to-pulse modulation and is smaller or of similar time scale as the expected (diffractive and refractive) scintillation time scales ($\Delta t_{\rm DISS} \sim 17$ min, $\Delta t_{\rm RISS} \sim 2.5$ d). We compute the scintillation dominated modulation index, $m_{\rm ISS}$, from this integrated data. The averaged systematic variation is then subtracted. The left-over, short-term variations are considered to be a measurement for the intrinsic flux density, and hence its modulation index, $m_{\rm int}$, is derived. The variation of $m_{\rm ISS}$ and $m_{\rm int}$ are plotted in Figure 4(b). The averaged $m_{\rm ISS}$ is $\sim$0.20 which is in good agreement with the theoretical prediction of $\sim$0.23 (Kramer et al. 2003). We note here that the individual points vary widely from this average value, and the intrinsic flux density modulation index $m_{\rm int}$ is about twice as much as the ISS modulation $m_{\rm ISS}$, but of less variation range.

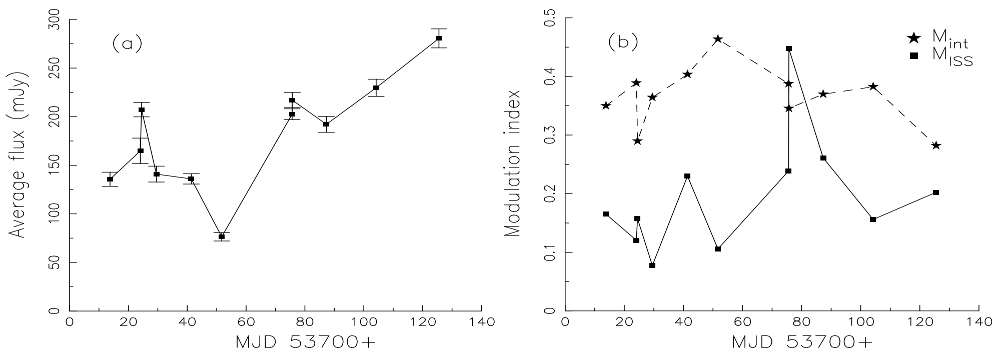

Fig. 4 (a)The time variation of the mean flux densities of PSR B0329+54. The error bar is 1σ rms. (b) Modulation indices of flux densities for each observation, considering both ISM and intrinsic variations.

4 CONCLUSIONS

We regularly monitored the flux density variation of PSR B0329+54 at 1540 MHz for four months. We detected three mode changing events. Statistically, for $\sim$15% of the time the pulsar is in its abnormal mode. At the abnormal mode, the trailing component becomes weaker while the leading component did the opposite. We measured $m_{\rm ISS}$ and $m_{\rm int}$, the ISS and intrinsic-fluctuation dominated modulation indices, respectively. The $m_{\rm int}$ is much larger than $m_{\rm ISS}$, but vary in a smaller range.

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