INTENSITY DEPENDENCE OF THE PSR 0329+54 PULSE PROFILE

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Abstract

Following the analysis by Krishnamohan and Downs (1983) of the Vela pulsar, we have investigated the behavior of the core and outrider components of PSR 0329+54 by calculating pulse profiles at different pulse intensities. VLA observations of individual pulses from PSR 0329+54 at 1415 MHz were used in our analysis. Our investigation reveals the following dependencies upon increasing core peak intensity:

(*i*) earlier core arrival times,
(*ii*) decreasing separation of the left outrider relative to the core,
(*iii*) increasing separation of the right outrider relative to the core,
(*iv*) decreasing outrider-to-core peak intensity ratios, and
(*v*) essentially constant core width.

To explain these dependencies, we propose a simple model in which the location of the core centroid is altered near the neutron star surface. The model and data are consistent with the mode-switching signatures and magnetospheric absorption features known to exist in this pulsar.

Introduction

PSR 0329+54 provides a fertile laboratory for the investigation of pulsar radio emission. The strength and pulse activity of this pulsar make it ideally suited for the study of individual pulses. The pulsar also exhibits the phenomena of mode-switching and magnetospheric absorption. To investigate the pulsar emission mechanism and the phenomena displayed by this particular pulsar, we calculated pulse profiles of PSR 0329+54 at different values of total pulse intensity. A similar analysis was performed on the Vela pulsar by Krishnamohan and Downs (1983), hereafter KD. We discuss the PSR 0329+54 profiles in terms of the conal and core emission identified by Rankin (1983a).

Total intensity observations

VLA observations of PSR 0329+54 were conducted on August 27, 1989. The VLA was in the phased array mode in which the individual antenna signals are summed coherently to form a pencil beam. Two IFs of opposite circular polarization were configured for a center frequency of 1415 MHz and a 6.25-MHz bandwidth selected to reduce smearing due to interstellar dispersion. The IF signals were passed through a dual-channel detector and integrator and then were sampled at 605 μs per channel. The integration time was 1.2 ms. The gains of the IFs were determined with observations of both an unpolarized continuum source of known constant flux and blank sky. The sampled data was written to computer disk and eventually magnetic tape for off-line analysis. The average of the calibrated IF signals formed the total power measurements used in our analysis.

A logic signal synchronous with the array waveguide cycle (52-ms period with 2-ms duration) was sampled in addition to the detected signals. The transmission direction of the array communications waveguide is reversed for 2 ms out of every 52 ms in order to send antenna control commands and the local oscillator reference. During this time the pulsar signal is interrupted, so a sample-track-and-hold (STH) amplifier is used to retain the value of the detected signal across the 2-ms data dropout, thus avoiding a detector transient when the signal resumes. By testing this logic signal, samples obtained during the control phase of the waveguide switch cycle were rejected in the analysis.

Gated pulse profiles

Before calculating pulse intensity profiles, the data were smoothed by a running average of pulse intensity in an attempt to eliminate modulation by interstellar scintillation. The total flux of the pulsar was then calculated for each period. A single pulse was assigned to one of ten adjacent intensity intervals (hereafter called gates) based upon the total pulse flux, *i.e.* to gate g if the flux, S, was in the intensity range $S_g < S \leq S_{g+1}$. All pulses assigned to gate g were averaged to form the profiles in figure 1.

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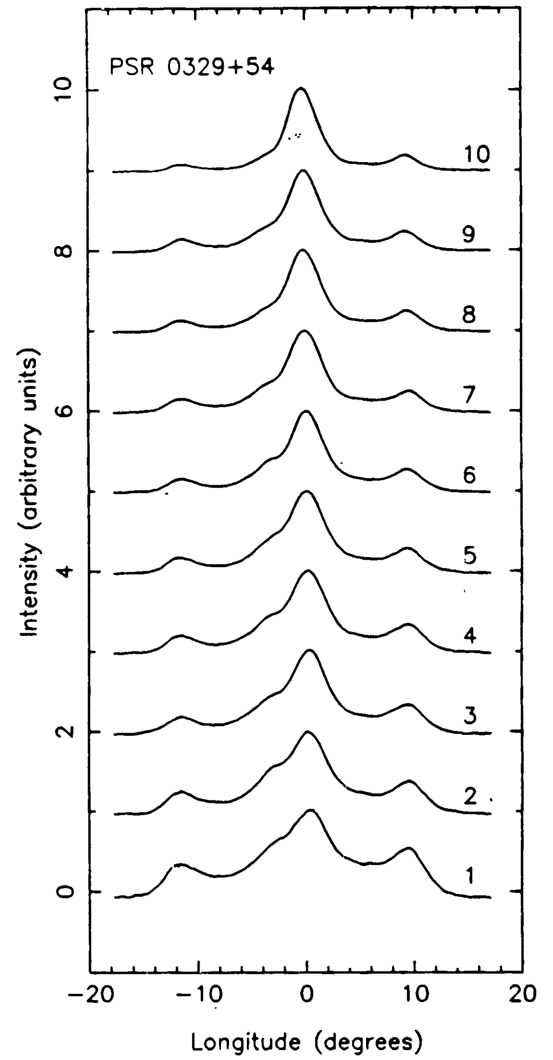

Figure 1 Intensity dependence of the PSR 0329+54 pulse profile. Pulse intensity increases from gate 1 to gate 10.

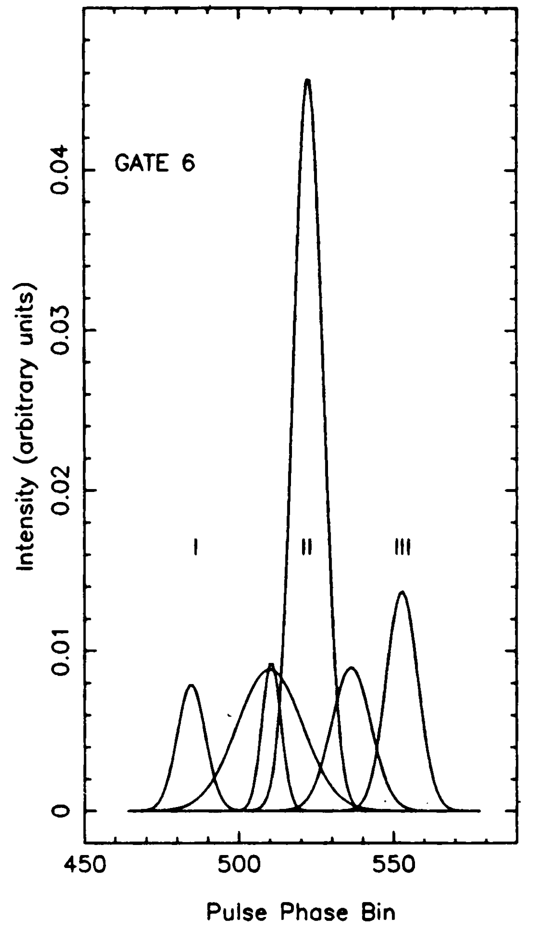

Figure 2 Gaussian components used to model gate 6.

Gate 1 of figure 1 shows the average profile of the least intense pulses and gate 10 shows the average profile of the most intense pulses. A total of 1805 pulses were used to produce the profiles in figure 1. The profiles were modelled as a sum of Gaussian components. Best fits to the profiles were found by minimizing the χ^2 calculated from the model and the data. Figure 2 shows the individual Gaussian components for gate 6. All gates are composed of two outrider components, a core component, bridges between the core and outriders, and a broad component which spans much of the profile width. Our discussion will be limited to the components labelled I, II, and III in figure 2 because the physical significance of the remaining components is questionable. The fits to the profiles reveal the following dependencies upon increasing core peak intensity: (*i*) earlier core arrival times, (*ii*) decreasing separation of the left outrider relative to the core, (*iii*) increasing separation of the right outrider relative to the core, (*iv*) decreasing outrider-to-core peak intensity ratios, and (*v*) essentially constant core width.

Discussion

The most obvious result of our analysis, as shown by figure 1, is that the more intense core components arrive earlier in time. A similar result was found by KD for the core of the Vela pulsar. The temptation exists to follow KD in relaxing the constraints of radius-to-frequency mapping, and to interpret the varying arrival times as signatures of emission originating at different heights in the pulsar magnetosphere. The change in emission height of a given component between gates may be calculated using the equations for time delay due to retardation, aberration, and magnetic sweep-back (Phillips and Wolszczan 1990, Cordes 1978). KD also used the longitudinal separation of components in a single gate profile to calculate the relative placement of the components within the Vela pulsar magnetosphere. By analyzing their data in this manner, KD assumed that the component which occurs first, as counted from left to right, in the gate profile also originates at the largest distance from the stellar surface. We hesitate to apply this reasoning to PSR 0329+54 because the implication would be to place component I at a larger distance from the stellar surface than component III. If components I and

III are conal emission as we suspect, they should originate at approximately the same height. We also hesitate to apply the time-of-arrival/emission height argument to component II of PSR 0329+54, because it is the core component of the pulsar and should originate close to the stellar surface (Rankin 1990). Rankin's suggestion that the core width is geometrical in origin, implies that the core width should remain essentially constant regardless of the core intensity as revealed by our fits (item *v*). The time-of-arrival/emission height argument applied to the Vela pulsar forced KD to place the narrow, and most intense, component furthest from the neutron star, which is contrary to what one might expect if a radiating region at a particular height spreads across the cone defined by open field lines.

To account for the early arrival times of the more intense pulses, we propose that the region on the stellar surface where the core emission is excited moves or is altered to produce the intensity dependent profiles. A schematic diagram of our simple model is shown in figure 3 as a view of the polar cap down the magnetic axis. The more intense profiles are produced when strong core component intensity contours are aligned along our line of sight. If the core (component II) moves away from component I such that our line of sight intersects weak core component intensity contours, the I-II component separation increases and the II-III component separation decreases as suggested by our fits (items *ii* and *iii*). The beam width (FWHM) of the core component is the same for both cases if the core angular intensity distribution is described by a bivariate Gaussian (Rankin 1990). The FWHM of a bivariate Gaussian is invariant along any set of parallel paths. Our simple model also suggests that the outrider-to-core relative intensity will most likely decrease with increasing core peak intensity, in agreement with what we observe (item *iv*).

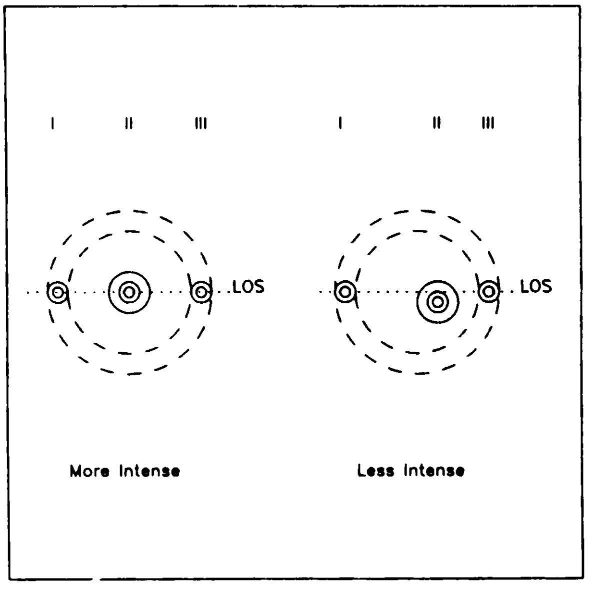

Figure 3 The relocation of component II relative to components I and III which is suggested as an explanation for the intensity dependence of the pulse profile.

If our model is correct, one may estimate how far the core emission excitation region moves on the stellar surface given the difference in times-of-arrival of the core peak for each gate with $s = R\theta = 2\pi R\Delta t/P$, where R is the stellar radius, and P is the pulsar period. Using the difference in arrival times of the core component in intensity gates 1 and 10 and a stellar radius of 10 km, we calculate that the core emission excitation region of PSR 0329+54 moves a distance of $s = 130$ meters.

By stating that the core emission excitation region moves, we do not mean to imply that the magnetic field tied to the pulsar surface actually moves. The core emission excitation region could be a small portion of the polar cap which is active in exciting radiation of varying intensity. Differential absorption could also be occurring over the polar cap, causing the apparent variation in intensity. Evidence exists for magnetospheric absorption in this pulsar. In fact, the narrow component immediately to the left of the core component is thought to be a portion of the core which has been absorbed (Rankin 1983b). Our data imply these components may be physically connected because their relative intensities and separations remain essentially constant with increasing core peak intensity. The location of absorption of the core emission identified by Rankin is consistent with the scenario proposed in our model.

The core components in the low and high intensity profile gates bear strong resemblances to the abnormal and normal emission modes, respectively, found in this pulsar. At 1.4 GHz, the more intense normal mode core component precedes the less intense abnormal mode core component (*cf.* figure 3 of Bartel *et al.* 1982). Inspection of individual pulses in our data set did not reveal mode-switching, so we suspect the effects documented by figure 1 are much more subtle than mode-switching. Mode-switching could possibly be an amplified version of our model, *e.g.*, a large change in the location of the core component emission excitation region on the stellar surface or a large variation in the absorption properties of the magnetosphere above the polar cap.