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A new model for nulling and moding in radio pulsars

Jaroslaw Dyks

Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, 87-100 Toruń, Poland
email: jinx@ncac.torun.pl

Abstract. Single pulse behaviour of radio pulsars is usually interpreted in terms of the $\mathbf{E} \times \mathbf{B}$ drift of a radio beam. It is shown that antisymmetric arrangement of the radio-bright zones can produce several types of observed single pulse phenomena: the half-cycle jump in subpulse modulation phase, left-right-middle subpulse sequence and switching between the core-dominated and cone-dominated pulsation modes. The geometry can also produce nulling, both sporadic and intermodal. The model implies that the radio-quiet intervals that separate the main pulse and interpulse in PSR B0826−34 correspond to azimuthal breaks in the radio beam, instead of breaks in colatitude.

Keywords. pulsars: general, pulsars: individual (PSR B0826−34, PSR B1237+25, PSR B1919+21)

The model: beam geometry and simulated pulse stacks

Single pulse modulation of radio pulsar signals involves the following striking phenomena: half-cycle jumps in subpulse modulation phase (eg. PSR B1919+21, fig. 3 in Prószyński & Wolszczan 1986), left-right-middle sequence of subpulse appearance within the pulse window (eg. PSR B1237+25, fig. 2 in Hankins & Wright 1980) and transitions between cone-dominated and core-dominated pulsation modes (eg. PSR B1237+25, fig. 5 in Srostlik & Rankin 2005). A special form of modulation are nulls that tend to separate different pulsation modes, but can also appear randomly in the modulation sequence. Changes of profile modes and nulling have also been observed in the Galactic centre magnetar PSR J1745−2900 (Yan et al. 2018), however, in this paper I focus on the peculiar single-pulse modulations as observed in the aforementioned normal pulsars.

Such types of modulations can be explained by an antisymmetrically zonal radio beam which is $\mathbf{E} \times \mathbf{B}$ drifting around the dipole axis at a drift period P_d. The beam is shown in grey in top row of Fig. 1 (in columns a, b, and c which correspond to different drift periods $P_d/P = 4.3$, 3 and 2.1). The solid lines with increasing numbers show consecutive paths of sightline that cuts the beam at a fixed distance β from the beam center once per spin period P (curvature of the cutting paths is neglected). The corresponding modelled pulse stacks are shown in the bottom part of the figure.

The beam consists of two radio bright zones (one closer to, another further from the dipole axis) that are located on the opposite sides of the dipole axis. Such antisymmetric arrangement results in the half-cycle jumps in modulation phase (case a, $P_d = 4.3P$). In case b ($P_d = 3P$) the left-right-middle sequence appears, as explained by the cutting paths on top. When the beam's inner zone is made asymmetric and $P_d = 2.1P$ (case c), then the transitions between cone-dominated and core-dominated modes appear (column c, bottom). When the radio-loud subzones of the beam do not overlap in magnetic azimuth, the pulsation modes can be separated by nulls (case c). This happens when the line of

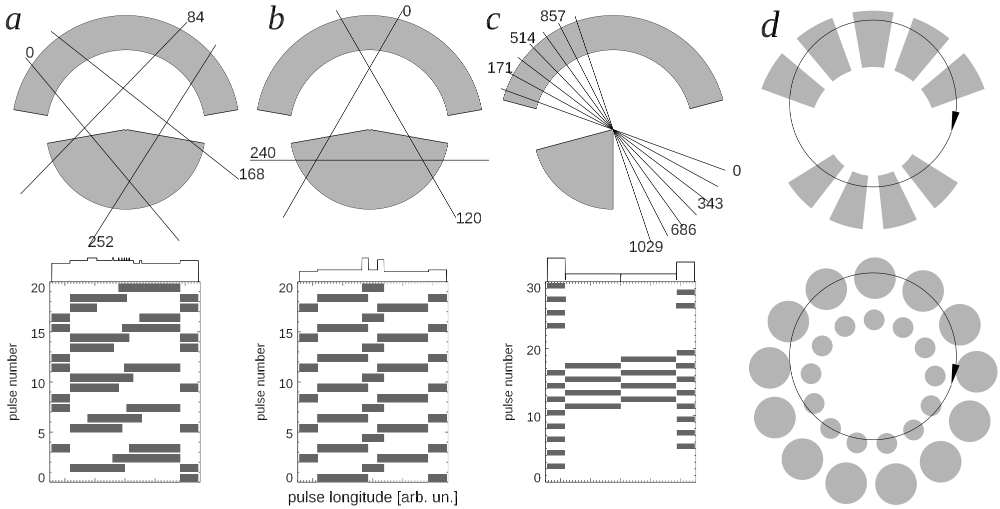

Figure 1. Columns a-c, top: head-on view of a radio beam (grey) with cutting paths of sightline for $P_d/P = 4.3$, 3 and 2.1 (left to right). Bottom: corresponding pulse stacks, with their sum shown on top. Column d: two beam models for PSR B0826−34. For more details see text.

sight is passing through the radio quiet parts of the drifting beam, while missing the radio loud (grey) parts entirely. Short random nulls are also possible (case a, pulse no. 5).

Since the cases b and c are observed in single object (B1237+25) it seems that both P_d and the beam shape change in this object on timescale of tens of spin periods. Assuming a near-central cut through the beam, the nulls observed in B1237+25 suggest that the beam has non-emitting breaks (voids) within some intervals of the magnetic azimuth (eg. cases b,c, top). Therefore, a simpler beam with two large voids in azimuth (column d, top) instead of a void in colatitude (d, bottom) can be proposed to explain the low-flux minima between the main pulse and interpulse in B0826−34 (Esamdin et al. 2005). The fine azimuthal structure (the split into 4 and 5 subbeams: column d, top beam) is introduced to reproduce the observation of subpulses in B0826−34 (cf. fig. 10 in Esamdin et al. 2005), however, a time-modulated beam without the fine structure could also be used. For more information see Dyks (2021, note, however, the following erratum: the value of P_d for the third case in fig. 4 therein should be corrected to $2.1P$).

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