On the origin of drifting phenomenon in pulsars

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Outline

- Theoretical background
  - The carousel model
  - Polar cap physics
- The numerical model
  - Bi-drifting pulsars
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- An alternative model?
The individual pulses consist of subpulses which, in many cases, exhibit systematic variation in position or intensity or both.
The carousel model

(Ruderman & Sutherland, 1975)

A group of localized discharges ("sparks") circulate around the magnetic pole of the neutron star.

In parts of the polar cap sparks move faster than the corotation

The $E \times B$ drift is around the rotation axis not the magnetic axis!

For the non-dipolar structure of surface magnetic field the magnetic axis may be beyond the polar cap

The carousel model can explain variety of pulsar data (e.g., Gil & Sendyk 2000; Gil & Mitra 2001; Gil et al. 2003; Weltevrede et al. 2006, 2007; Herfindal & Rankin 2007; Rankin & Wright 2008; Herfindal & Rankin 2009, ...).
The electric and magnetic fields within a region of spark formation with screened acceleration (the left panel) and during the discharge (the right panel).
The electric field (the white arrows) across the polar cap for random distribution of sparks. The color map corresponds to the electric potential.

The electric potential of a single spark:

$$V' \propto \ln(r_s)$$

$$\tilde{E}'_\perp = -\nabla V'$$

The drift velocity:

$$\vec{v}_{dr} = \frac{c(\tilde{E}_\perp \times \vec{B})}{B^2}$$
Plasma velocity at the polar cap

[Graph showing plasma velocity vectors at different angles (θ rad) on a circular plot.]
The numerical model

- neutron star setup (pulsar geometry, magnetic field configuration)
- calculation of open magnetic field lines and lines connected to the line of sight (a, b)
- electric potential setup (c)
- simulation of sparks motion at the polar cap (c) and modelling of single pulses (d)
Bi-drifting phenomenon in PSR J0815+0939
(Szary & van Leeuwen, 2017)
Bi-drifting phenomenon in PSR B1839-04

Drifting subpulses
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Plasma between spark forming regions rotate around the electric potential extremum (minimum or maximum) at the polar cap.

The location of spark forming regions (sparks) is determined by plasma between sparks.

The modified carousel model provides physical insight into the polar cap region (surface magnetic field, electric potential variation).

"The drift velocity depends [...] on the variation of the accelerating potential across the polar cap" (van Leeuwen & Timokhin, 2012)
An alternative model?

The corotation model vs The carousel model

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$P_3(\dot{E})$ - Basu et al. 2016

Drifting subpulses

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$P_3(\dot{E})$ - raw data

![Graph showing the relationship between $P_3$ and $\dot{E}$ with data points and fitted lines.](image-url)

- **Basu et al. 2016**
- **ND fit**
- **PD fit**

$P_3$ in $P$ vs. $\dot{E}$ (erg/s)

- $P_3$ in $P$ on the y-axis
- $\dot{E}$ (erg/s) on the x-axis

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$P_3(\dot{E})$ - the modified carousel model

![Graph showing the relationship between $P_3$ in $P$ and $\dot{E}$ (erg/s). The graph includes data points for PD and ND fits, as well as aliased data. The graph is labeled with Basu et al. 2016, ND fit, PD fit, PD, ND, and aliased.](image-url)
Plasma in the open field line region can be described as multiple-vortex electromagnetic tornado. The faster the tornado rotates, the faster the pulsar loses its spin-down energy.
Thank you!

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