Abrupt Changes in Pulsar Pulse Profile Through Multiple Magnetospheric State Switching

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Physics of Neutron Stars – 2017, St Petersburg, Russia, 10–14 July 2017

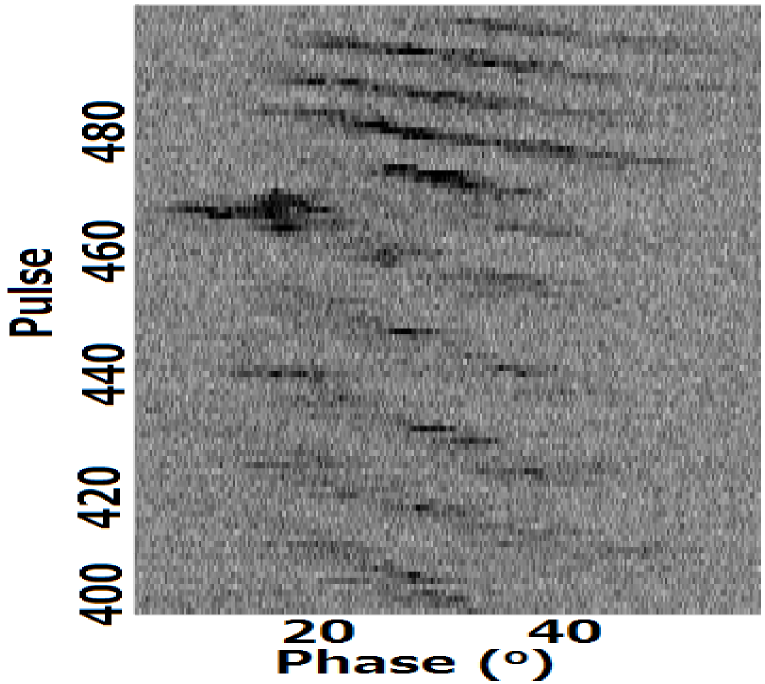
Outlines

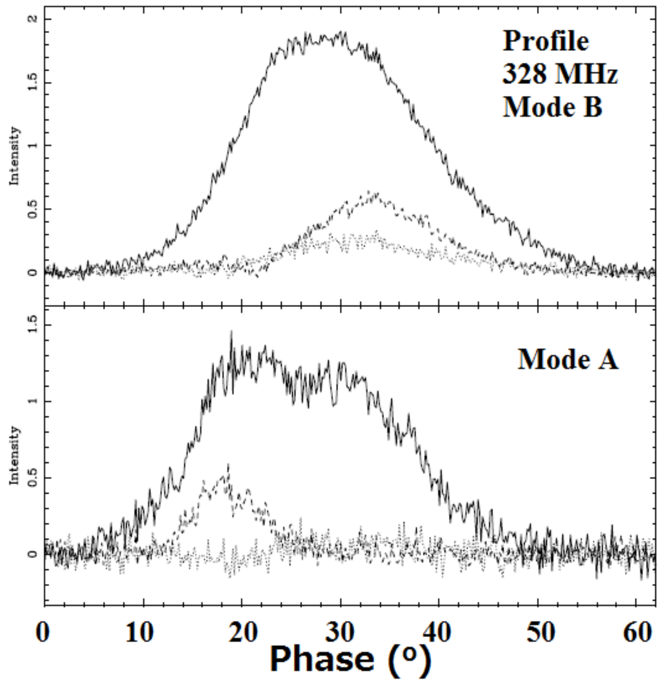
- Phenomena showing changes in emission properties.
- Sketch a model for multiple-state magnetosphere.
- Illustrations for changes as result of switching between different magnetospheric states.

WHAT IS CHANGING?

The phenomena:

- ‘ON’ and ‘OFF’ emission (Kramer et al. 2006); correlation between pulse shape and the spin-down rate (Lyne et al 2010); nulling of 3 discrete timescales (Kerr et al. 2014)…
- changes in emission mode → changes in subpulse drift rates → changes in profile properties (e.g., B0031-07, Smits et al. 2005)





The need for more states

- Discrete variations in these emission properties imply:
  - multiple emission ‘states’ in the magnetospheres;
  - different pulsars have different sets of allowed states;
  - a pulsar behaves as if a ‘normal’ pulsar in each state.

- Let’s give it more ‘states’:
  - multiple magnetospheric emission states (y) to switch into (Melrose & Yuen 2014);
  - each defined by unique $\boldsymbol{E} = \boldsymbol{E}(y)$;
  - switches between different states can occur **abruptly** or **steadily**.

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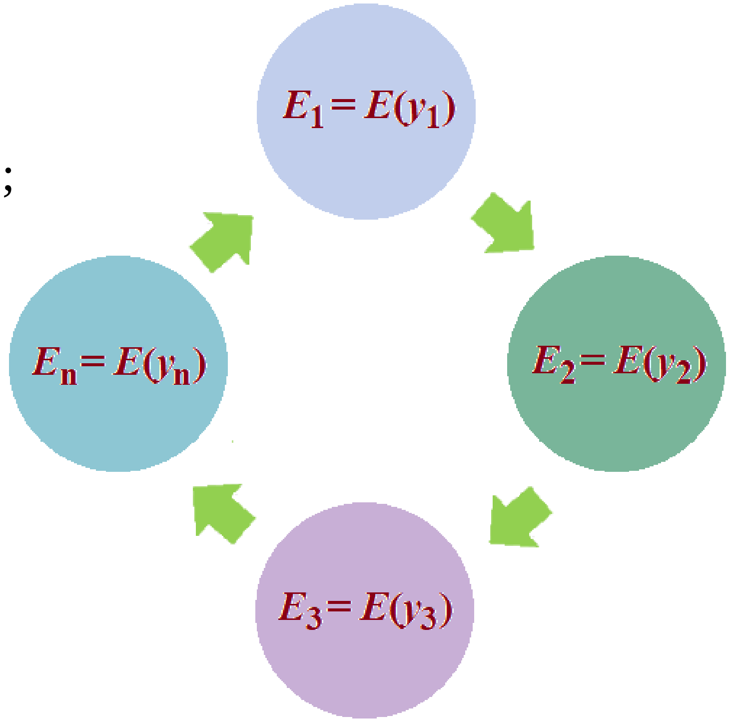


Observing effects

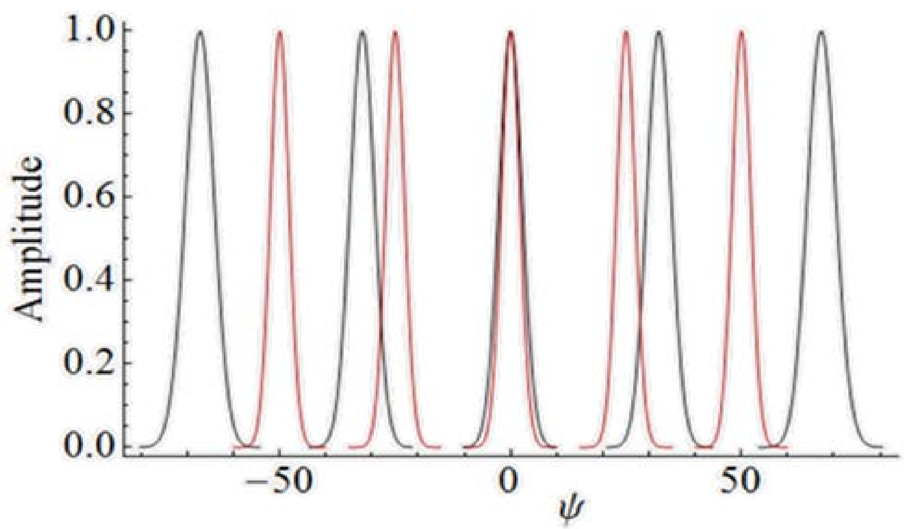
- Magnetospheric states (y := [0,1]) $\boldsymbol{E} = (1 - y\boldsymbol{b}\,\boldsymbol{b}) \cdot \boldsymbol{E}_{\rm ind} - (1 - y)\mathrm{grad}\,\Phi_{\rm cor}$

$$\boldsymbol{v}_{\rm dr} = y\,\boldsymbol{v}_{\rm ind} + (1 - y)\,(\boldsymbol{\omega}_* \times \boldsymbol{x})_\perp$$

- Apparent 'relative' subpulse drift:

$$\omega_{\rm R}(y) = m\omega_{\rm dr}(y) - \omega_{\rm V}$$

- For $\omega_{\rm V} \neq 0$ or $\omega_{\rm V} = 0$:
  - path through the polar region and duration of stay in the region are different.
  - profile displacement and broadening.



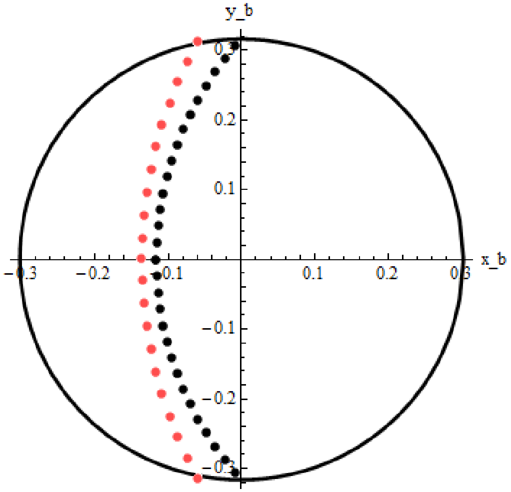
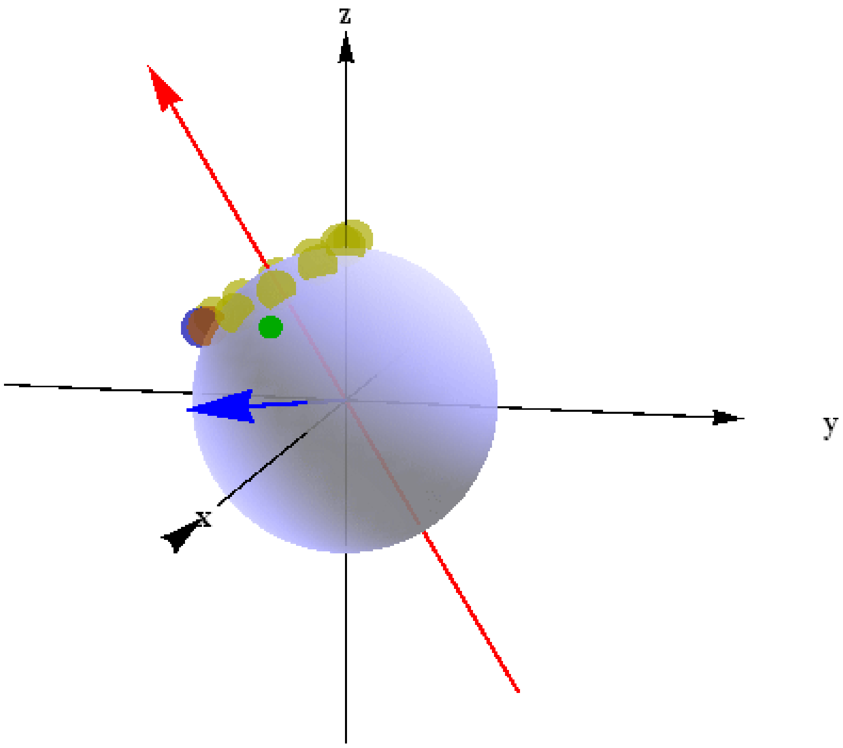


Illustration: simple case

- A sudden switch in the magnetosphere, as reflected by a change in the subpulse drift rate, causes the profile characteristics to change.

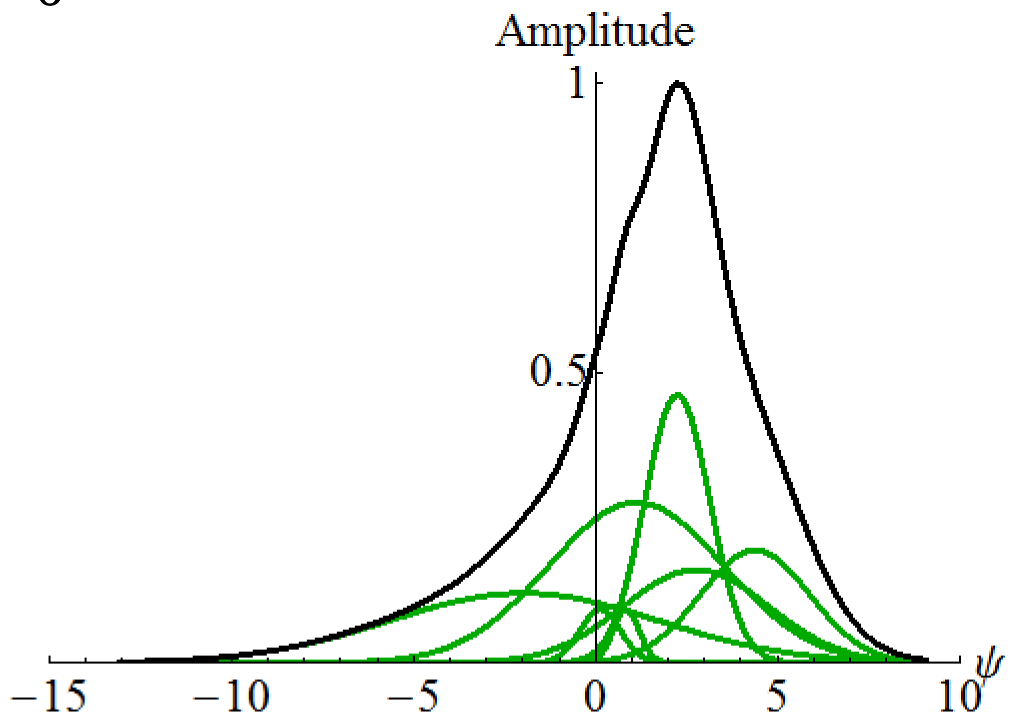
Emission spot	**Peaks at $\psi = 0^o$ (blue)**	
State	$\omega_V = 0$	$\omega_V \neq 0$
Pulse-width	27^o	35^o
Peak phase	0^o	0^o

Emission spot	**Peaks at $\psi = -23^o$ (brown)**	
State	drift $=0^o$	drift $=50^o$
Pulse-width	35^o	39^o
Peak phase	-23^o	-26^o



Changes in profile

- Profile shape is unique to the magnetospheric state.
  - the components shift within the fixed pulse window.
- Simulation using ζ=58.1^o, α= 53^o.
- Magnetospheric state: y=0



Changes in profile

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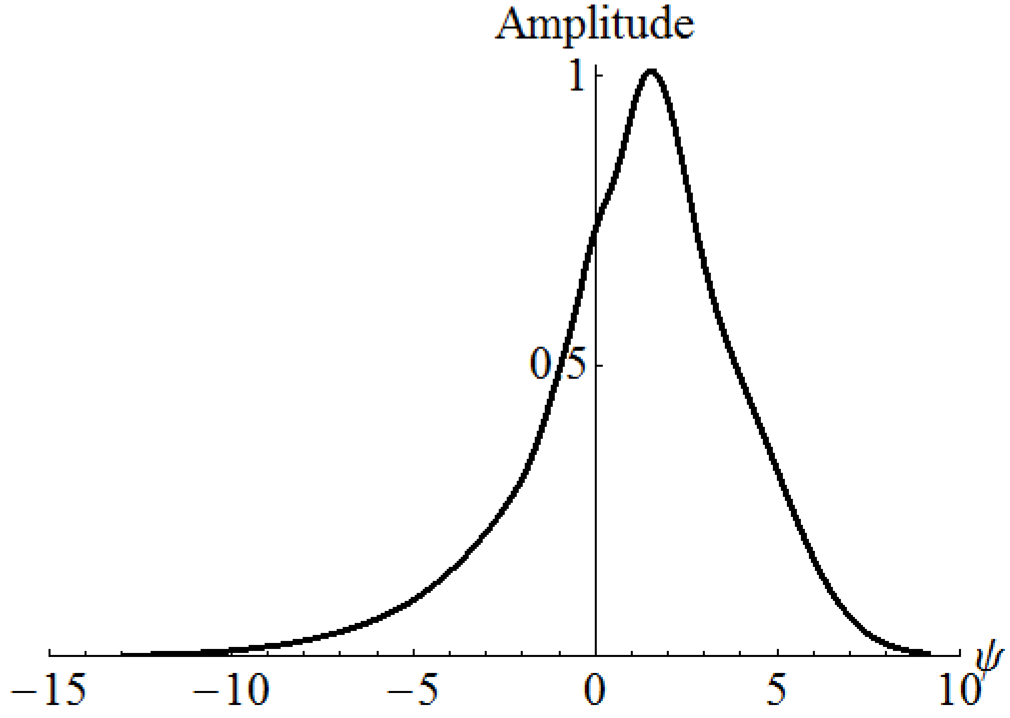
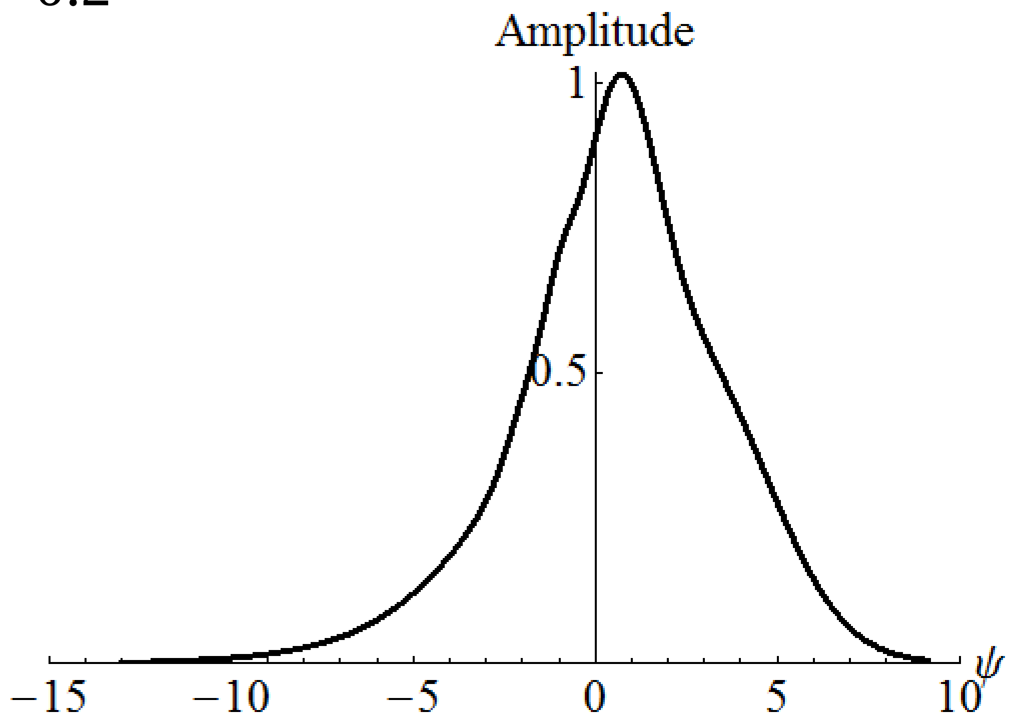
  - the components shift within the fixed pulse window.
- Simulation using $\zeta=58.1^o$, $\alpha= 53^o$.
- Magnetospheric state: $y=0.1$



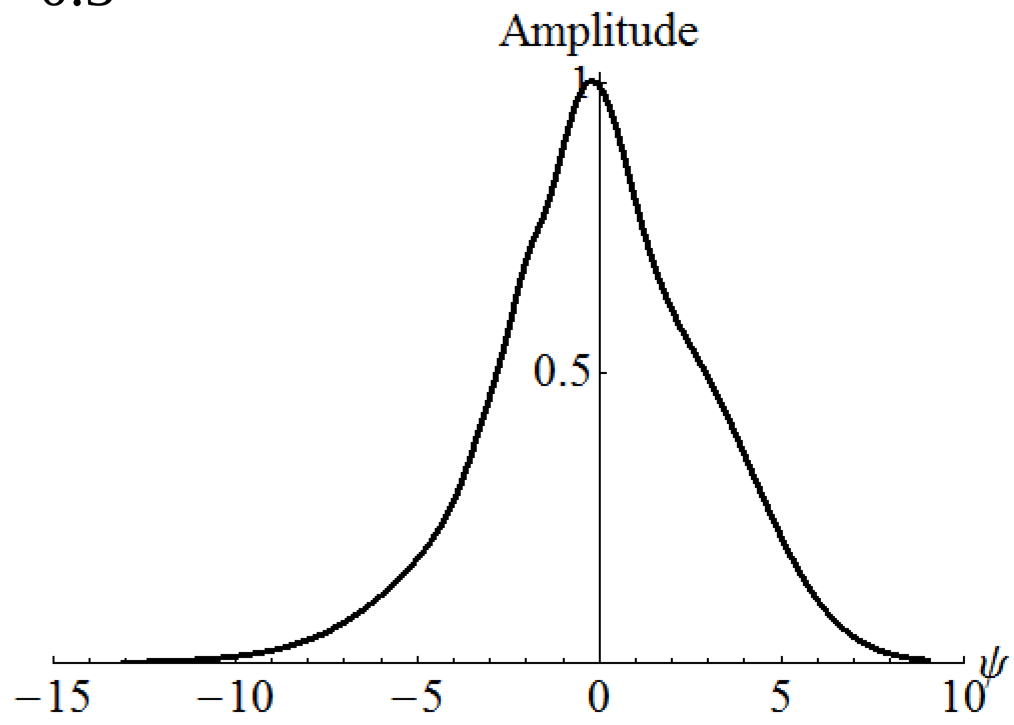
Changes in profile

- Profile shape is unique to the magnetospheric state.
  - the components shift within the fixed pulse window.
- Simulation using ζ=58.1^{o}, α= 53^{o}.
- Magnetospheric state: y=0.2



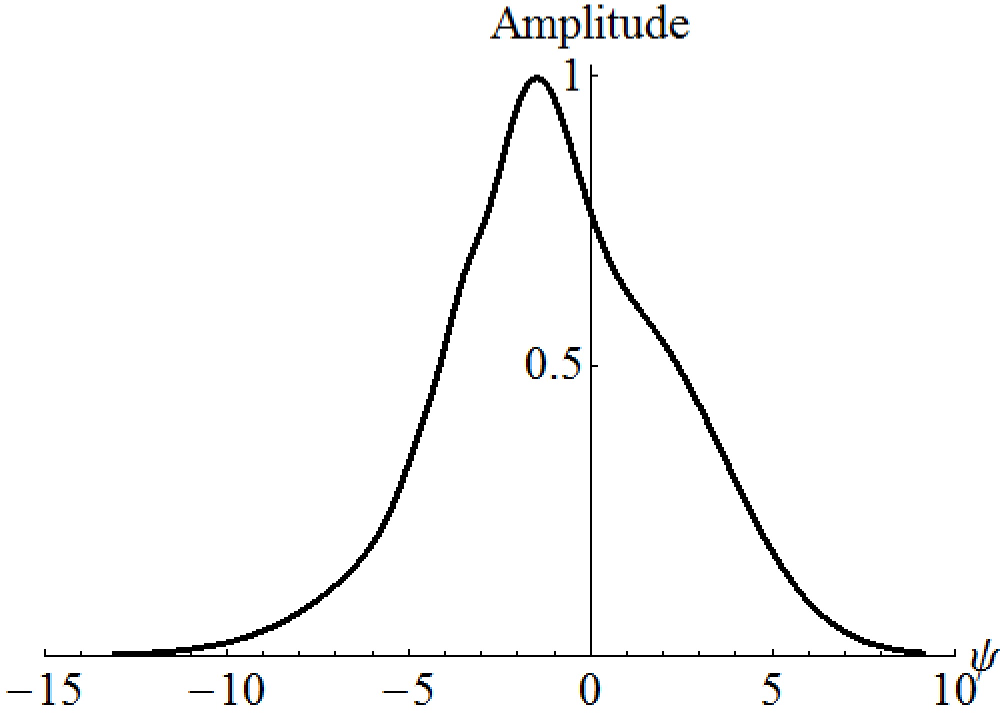
Changes in profile

- Profile shape is unique to the magnetospheric state.
  - the components shift within the fixed pulse window.
- Simulation using ζ=58.1°, α= 53°.
- Magnetospheric state: y=0.3



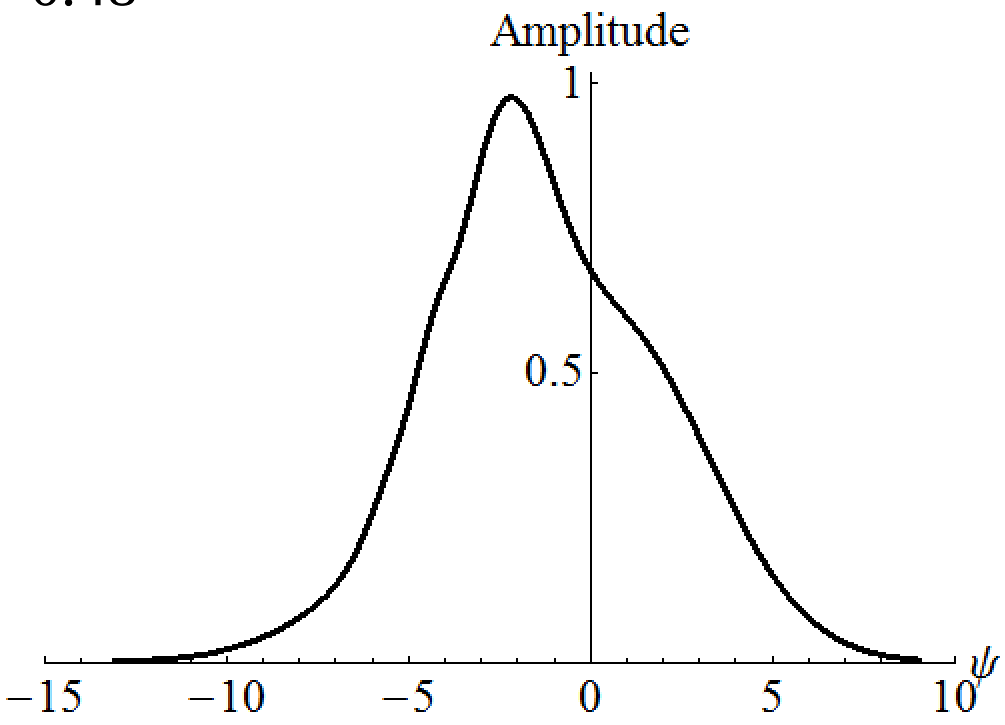
Changes in profile

- Profile shape is unique to the magnetospheric state.
  - the components shift within the fixed pulse window.
- Simulation using ζ=58.1^o, α= 53^o.
- Magnetospheric state: y=0.42



Changes in profile

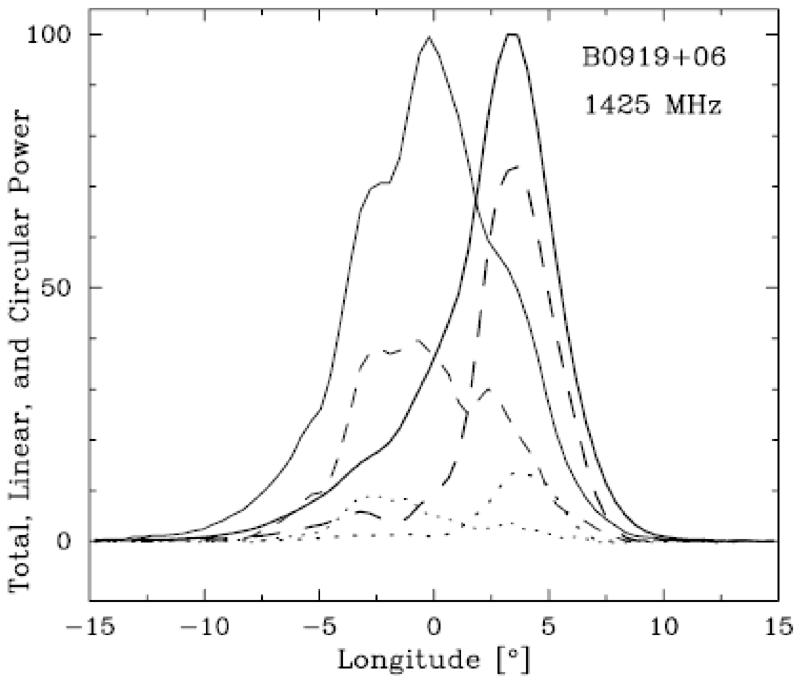
- Profile shape is unique to the magnetospheric state.
  - the components shift within the fixed pulse window.
- Simulation using $\zeta=58.1^{o}$, $\alpha= 53^{o}$.
- Magnetospheric state: y=0.48

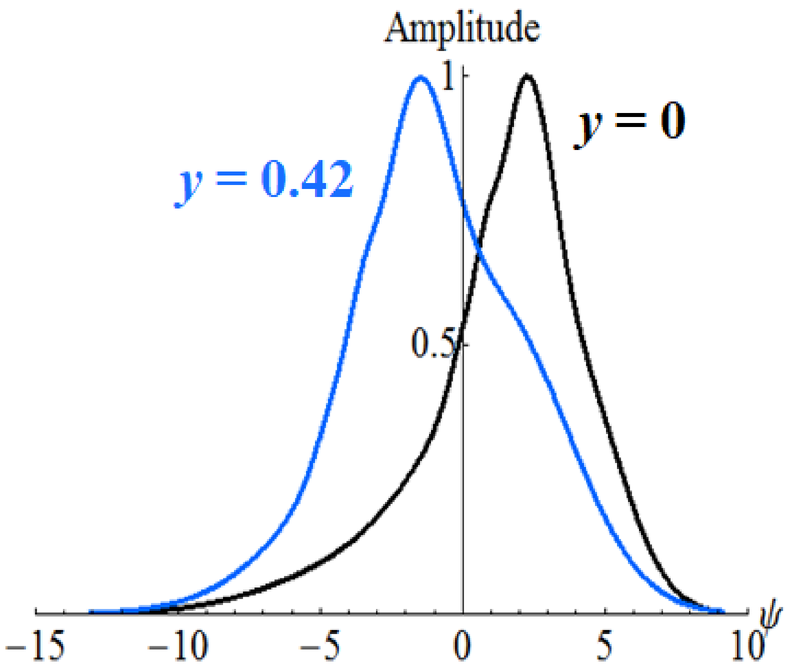


A case study: B0919+06

- Switching in *y* from 0 to 0.42 results in (i) a shift in the profile peak by ~4^{o}; and (ii) changes in the profile shape.
- Limitations of the model:
  - shifted profile shape indicate other mechanisms involved;
  - assume dipolar field structures.

(Rankin et al. 2006)





Things we don't know...yet

- **Cyclical switching:**
  - observations show recurring switching, or, in our language:

$$y_1 \rightarrow y_3 \rightarrow y_5 \rightarrow y_1 \cdots$$

  - can do it (simulationally), but don't know why it should (physically).
- **Pulsars that switch:**
  - traditional models make no distinction between pulsars with single and multiple states.
  - two groups of pulsars differ only in the switch rate: 'stable' corresponds to switching occurring too infrequently to have been observed.
- **Local vs global switching:**
  - implies whole magnetosphere switches simultaneously (through $\boldsymbol{E}$).
  - e,g., synchronized changes in radio and γ–ray emission properties?

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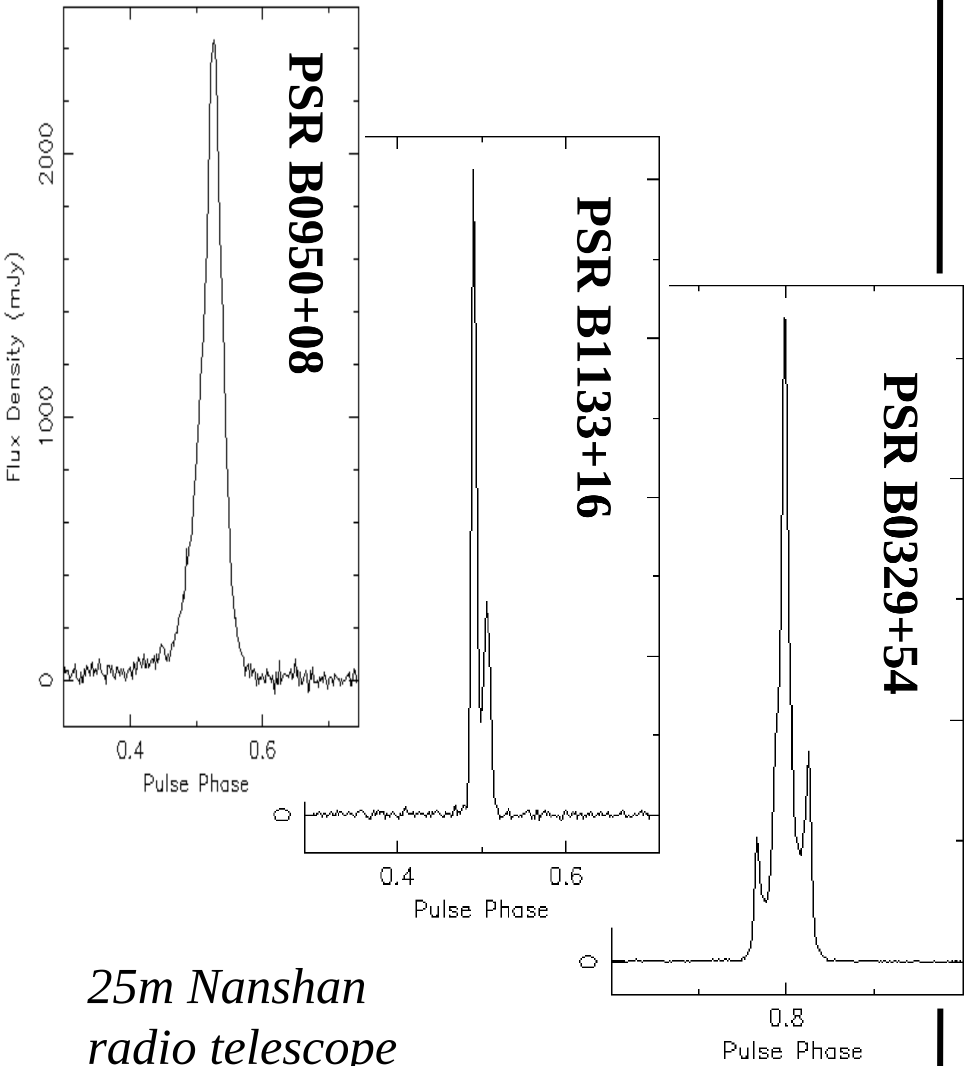
Conclusions

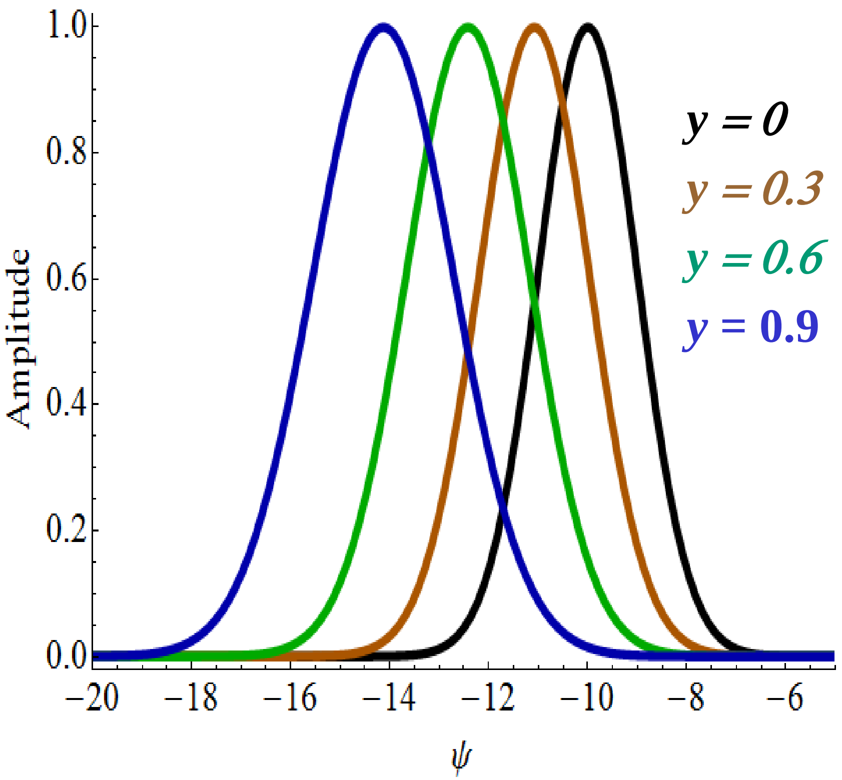
Profiles are unique to each ***pulsars***.



25m Nanshan radio telescope

Profiles are unique to each ***magnetospheric states*** of a pulsar.

Simulation with $\alpha = 20^{o}$; $\zeta = 10^{o}$



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- Clemens & Rosen, 2004, *ApJ*, **609**, 340
- Demorest, et al., 2013 *ApJ* **762**, 94
- Goldreich & Julian, 1969 *ApJ* **157**, 869
- Kramer, et al., 2006 *Science* **312**, 549
- Lyne, et al., 2010 *Science* **329**, 408
- Melrose & Yuen, 2014 *MNRAS* **437**, 262
- Rankin, et al., 2006 *MNRAS* **370**, 673
- Smits, et al., 2005, *A&A*, **440**, 683
- Yuen & Melrose, 2017, *MNRAS*, **469**, 2049

Thank you.

The model

- Magnetospheric plasma flow (y := [0,1])

$$\boldsymbol{E} = (1 - y\boldsymbol{b}\,\boldsymbol{b}) \cdot \boldsymbol{E}_{\text{ind}} - (1-y)\text{grad}\,\Phi_{\text{cor}}$$

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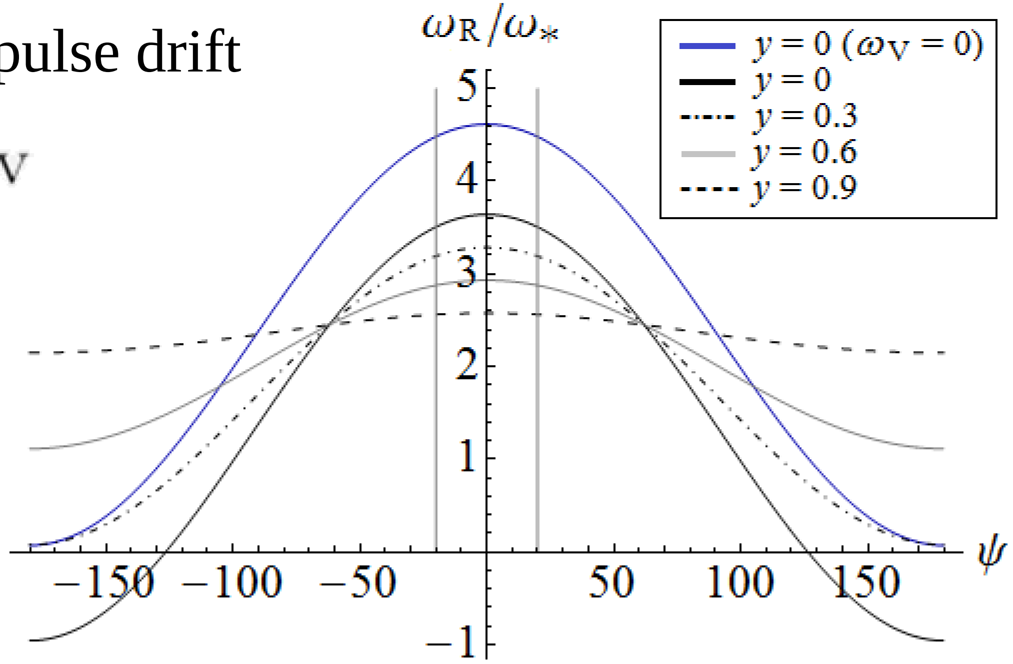
- Apparent 'relative' subpulse drift

$$\omega_{\text{R}}(y) = m\omega_{\text{dr}}(y) - \omega_{\text{V}}$$



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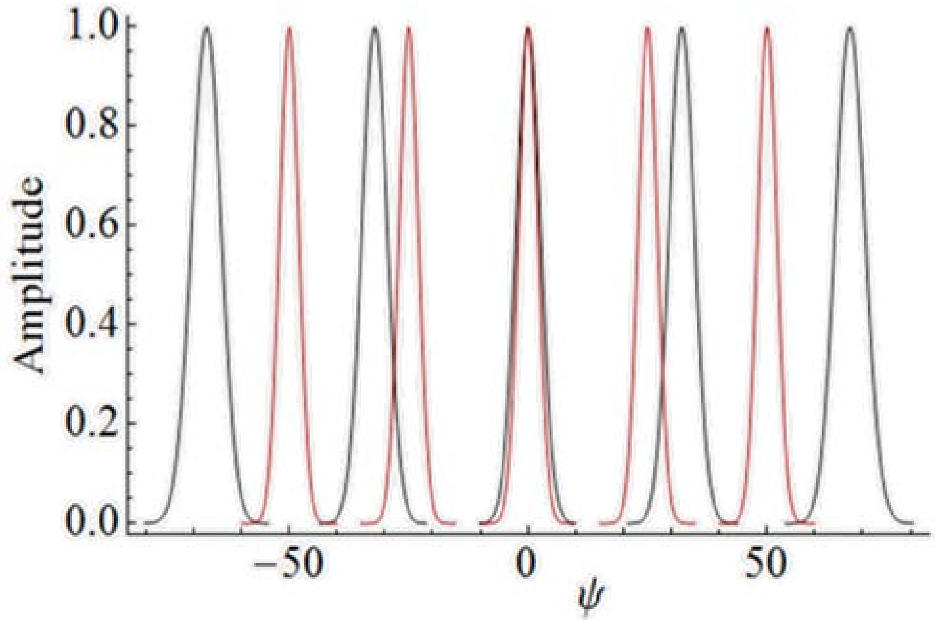
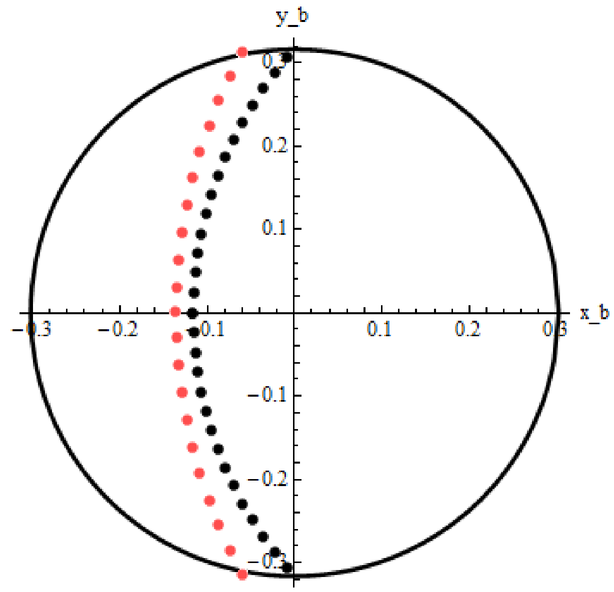
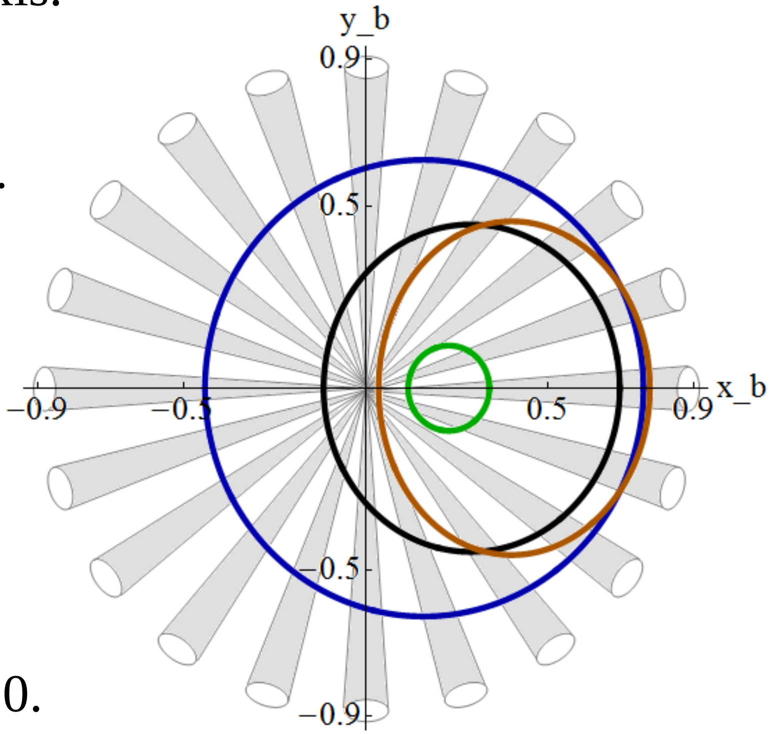




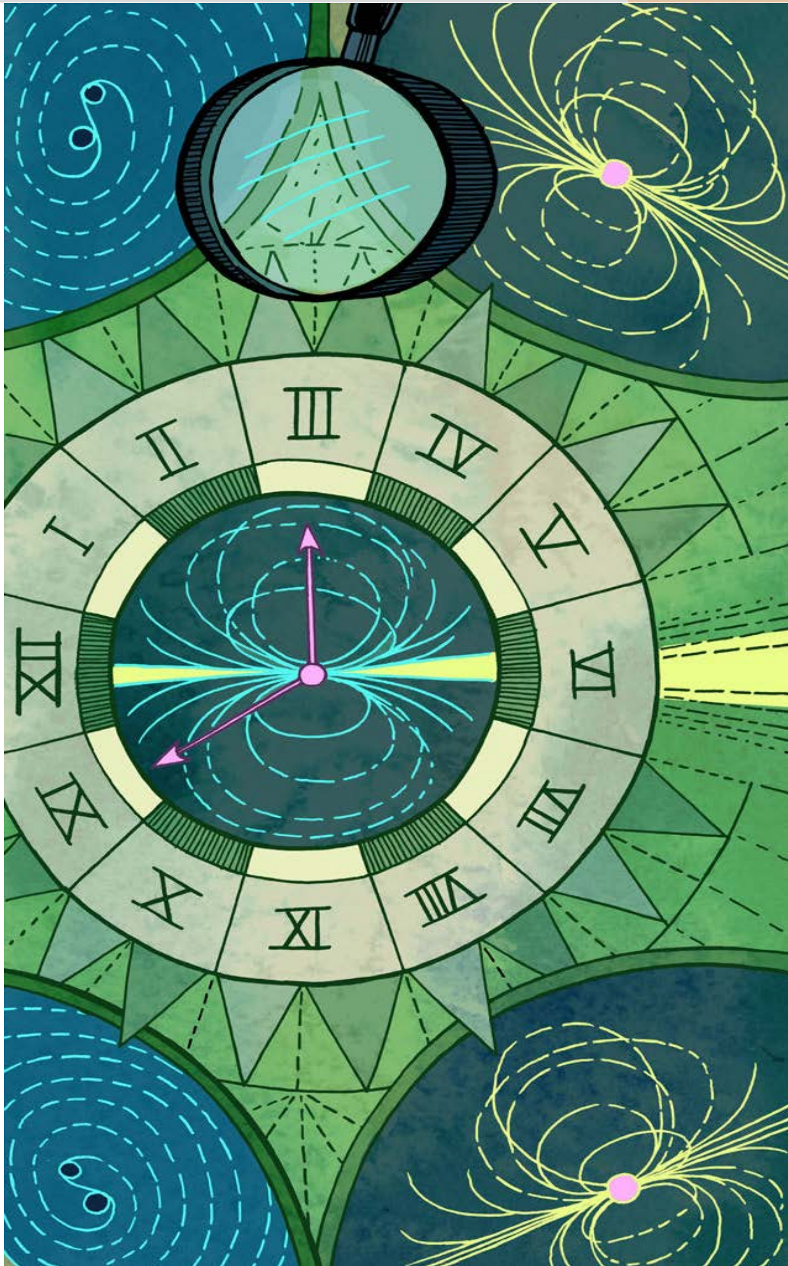
Visible emission

- Emission structure:
  - a wave at a specific spherical harmonic grows preferentially giving an emission pattern corresponds to *m* anti-nodes.
  - observer sees the anti-nodes flow past at $m\omega_{dr}$
  - anti-nodes arrange evenly around ***B*** axis.
- The ‘visible’ paths:
  - shape, size and location unique to ζ,α.
  - non-concentric and may not revolve around or concentric to the ***B*** axis.
- Anti-nodes visible **only if** on the visible path:
  - # of intersected anti-nodes is uneven along the path.
  - highest around the centre of pulse, $\psi=0$.



Conclusions

- Pulsar emission state switching is here to stay:
  - need to understand its properties;
  - more importantly, its influential parameters;
  - broader and deeper pulsar astrophysics.
- For other detection purposes:
  - e.g., GWs. Can’t be very confidence of a detection unless pulsar intrinsic properties are identified.
  - should be lots out there.
  - search for more candidates.
  - but before we can do that…



What is involved?

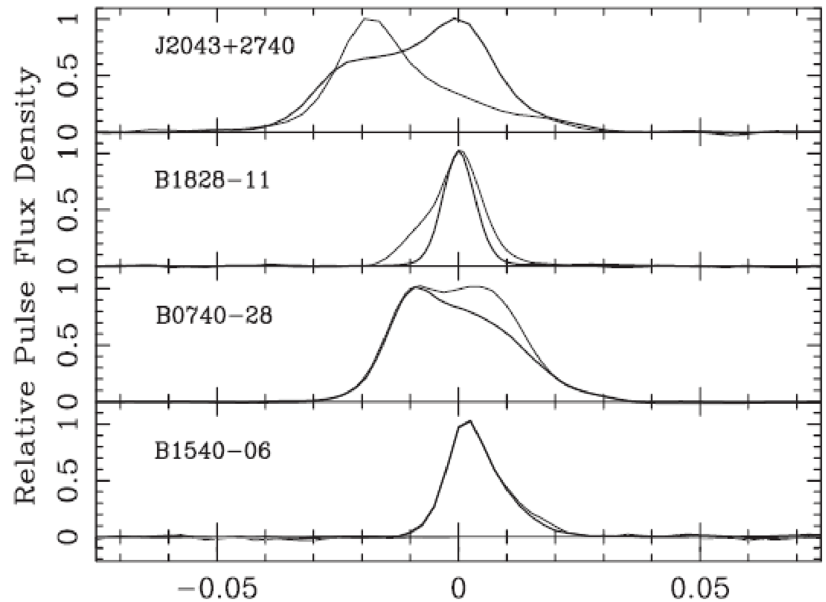
- Study finds strong correlation between profile shape and spin-down rate – suggests discrete switching between 2 magnetospheric states.

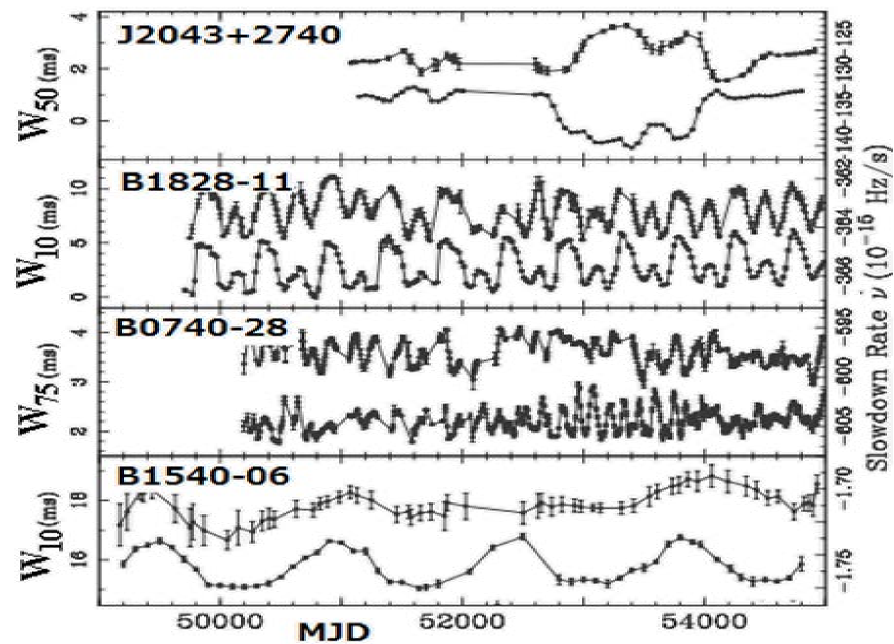
- An intermittent pulsar
  - **ON** for 5–10 days
  - **OFF** for 25–35 days
- Switching between 2 states: vacuum (off) and plasma (on).

$$\frac{\dot{\nu}_{\mathrm{ON}}}{\dot{\nu}_{\mathrm{OFF}}} = 1.5$$

$$\Psi_P = \Psi_P(S_E)$$
$$S_E = S_E(\dot{\nu}) \quad \rho \quad E$$

(Lyne et al. 2010)





What are we missing?

- **Variations in:**
  - drifting subpulses of multiple drift modes (Smits et al. 2005);
  - emission properties between ‘on’ and ‘off’ (Kramer et al. 2006);
  - profile shape + spin down rate (Lyne et al. 2010);
  - glitches (Keith et al. 2013);
  - nulling of three discrete timescales (Kerr et al. 2014);
  - you name it…
- **Common features:**
  - time-dependent; shows up as timing irregularities.
  - almost all accompanied with changes in spin-down rates.