Time-Dependent Events and the Stability in Pulsar Magnetospheres

by

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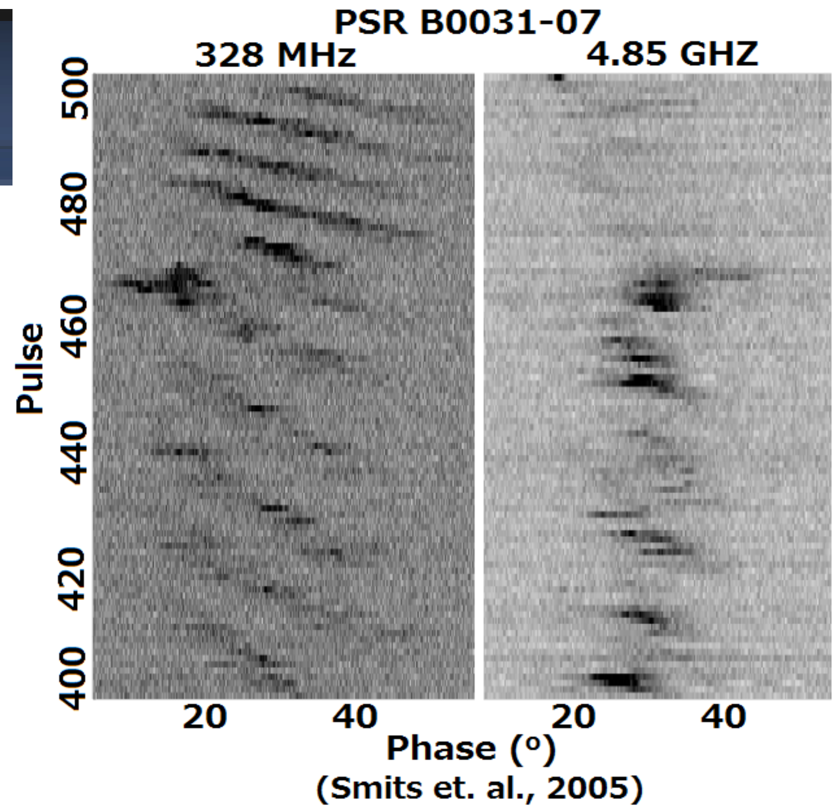
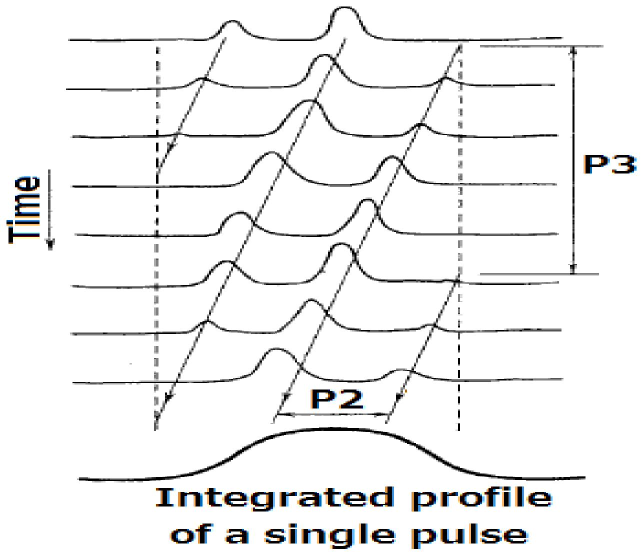
Time-dependency

- Time-dependent nature: nulling, mode-changing …
- Drifting subpulses
  - consecutive subpulses appear progressively at earlier rotational phases.
- Drift rate is not always constant.
  - switches at a given frequency.
  - different rates for different frequencies.
- Magnetospheric origin:
  - electric field causes drift across **B**.





Electric field and plasma drift velocity

- 2 Models for $\boldsymbol{E}$:
  - vacuum dipole model (VDM): $\boldsymbol{E} = \boldsymbol{E}_{\mathrm{ind}}$
  - corotating magnetosphere (G-J) model (CMM): $\boldsymbol{E} = \boldsymbol{E}_{\mathrm{ind}} + \boldsymbol{E}_{\mathrm{pot}}$
- Synthesis model (Melrose and Yuen, 2014):
  - minimal model: inductive $E_{//} = 0$ in VDM.
  - define class of synthesized model between the minimal model and the corotating model.
  - each synthesized model has different values of y:= [0,1], and different rotation states.

- Electric field: $\boldsymbol{E} = (1 - y\boldsymbol{b}\,\boldsymbol{b}) \cdot \boldsymbol{E}_{\mathrm{ind}} - (1 - y)\mathrm{grad}\,\Phi_{\mathrm{cor}}$
- Plasma drift velocity: $\boldsymbol{v}_{\mathrm{dr}} = y\,\boldsymbol{v}_{\mathrm{ind}} + (1 - y)\,(\boldsymbol{\omega}_* \times \boldsymbol{x})_\perp$

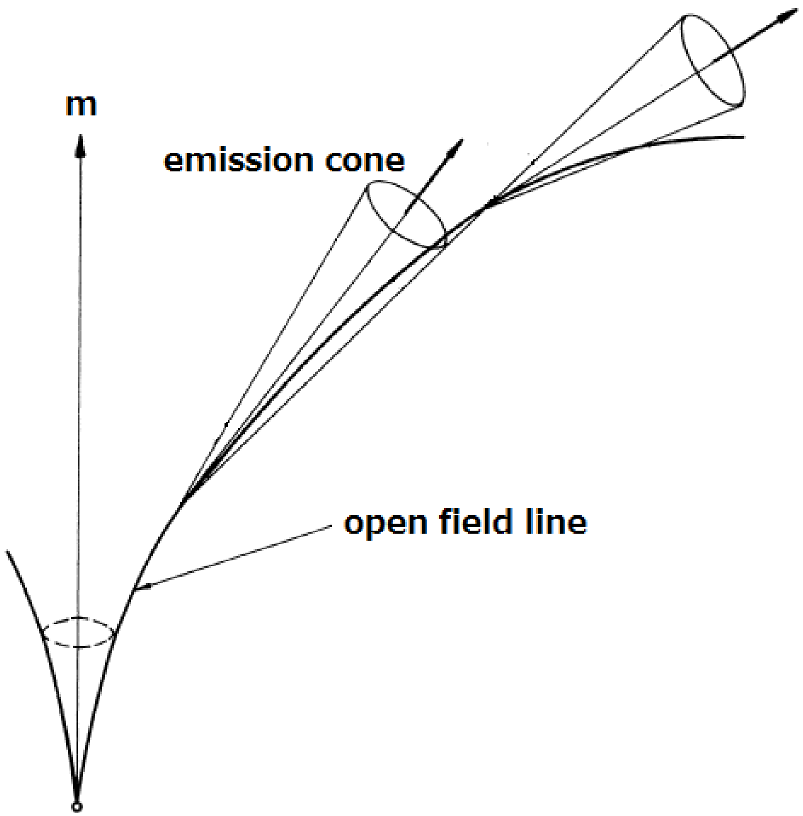
Pulsar visibility

- Determine the source points in the magnetosphere that a fixed distant observer can see emission.

- Assumptions:
  1. dipolar B lines (close to surface);
  2. emission is directed along B line tangent;
  3. emission only occurs within the polar cap region.

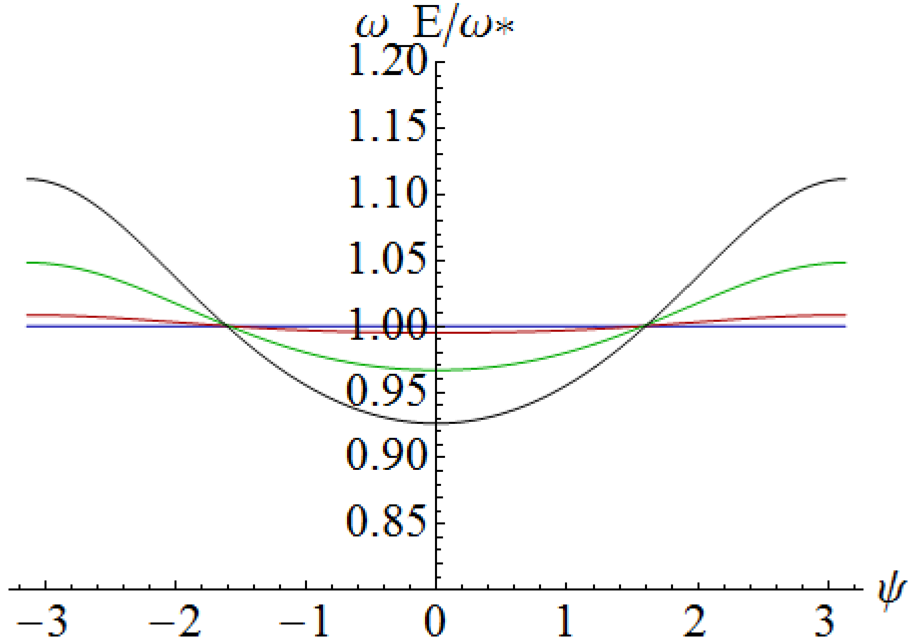
$$(\hat{\mathbf{b}} \cdot \hat{\mathbf{n}})^2 = 1, \qquad \hat{\phi}_b \cdot \hat{\mathbf{n}} = 0.$$

- Solutions depend only on ζ, α, ψ.



Speed of the emission point

- The geometry identifies the emission point on a field line.
  - stationary for an aligned rotator.
  - moves and traces out a closed path as the pulsar rotates for oblique rotator.
- Angular speed of the emission point is different from angular speed of the pulsar.
  - slower at near-side,
  - faster at far-side.

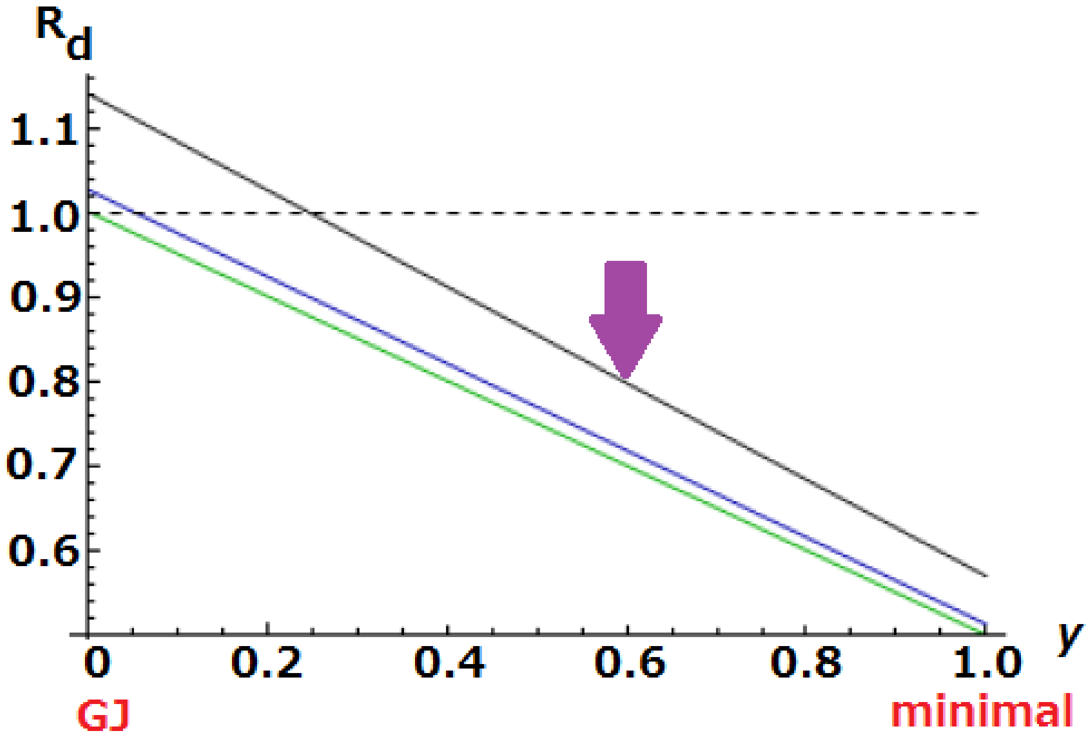


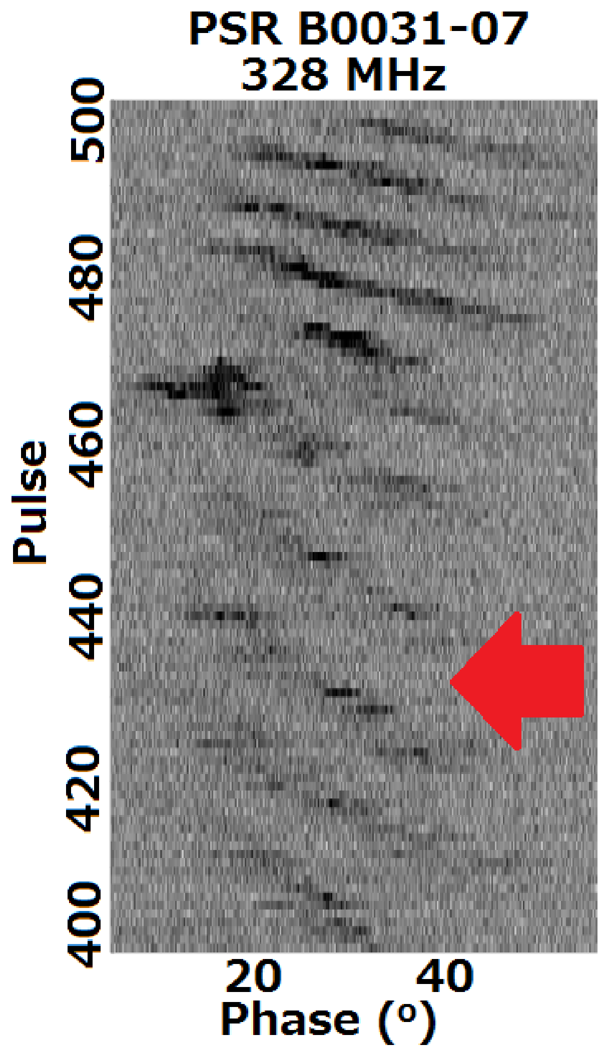
Velocities in pulsar magnetospheres

- 3 velocities:
  - spin frequency of the star, ω
  - angular speed of the emission point, ω_E
    - $\omega_{\mathrm{E}} = [(\dot{\theta}_{\mathrm{E}})^2 + \sin^2\theta(\dot{\phi}_{\mathrm{E}})^2]^{1/2}$
    - can be approximated by the phi component for narrow pulse width.
  - plasma drift velocity, $\mathbf{v}_{mag}$ or ω_{mag}
    - ignoring radial component
    - magnetospheric velocity: $v_{\mathrm{mag}\theta}, v_{\mathrm{mag}\phi}$
    - angular velocity: $\dot{\theta}_{\mathrm{mag}} = v_{\mathrm{mag}\theta}/r, \dot{\phi}_{\mathrm{mag}} = v_{\mathrm{mag}\phi/\mathrm{r}}$

Drift modes I

- Consider $R_d = \omega_{mag/}\ \omega_E$
  - varies as functions of α and ζ.
  - varies as a function of y

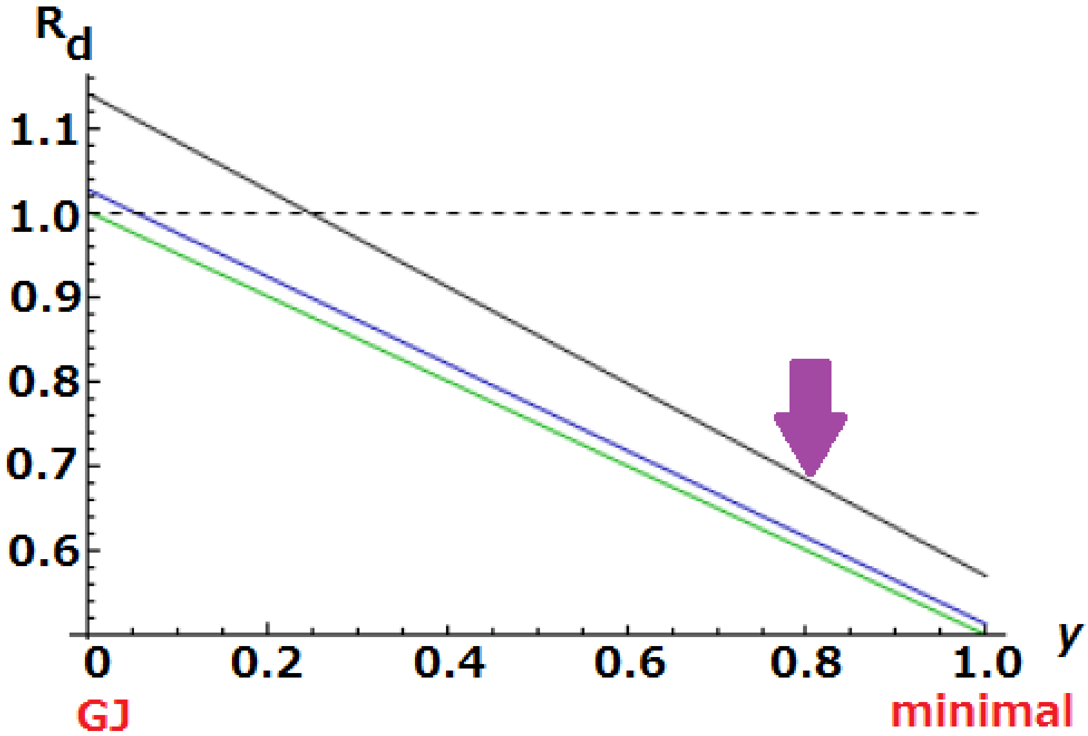


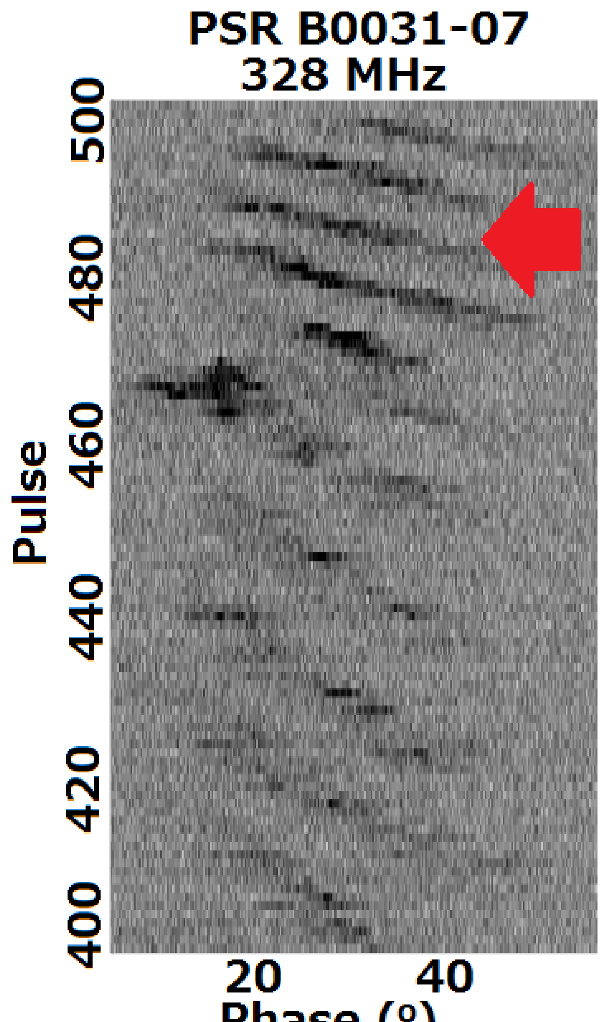


(Smits et. al., 2005)

Drift modes II

- Consider $R_d = \omega_{mag/} \omega_E$
  - varies as functions of α and ζ.
  - varies as a function of y

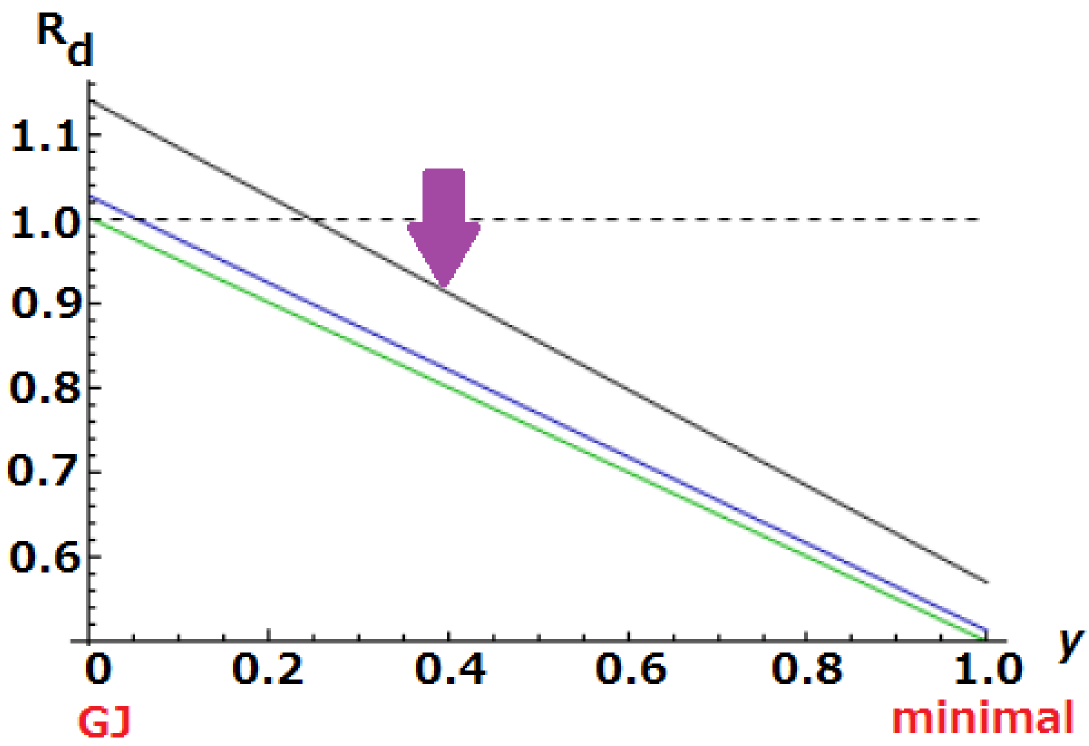




(Smits et. al., 2005)

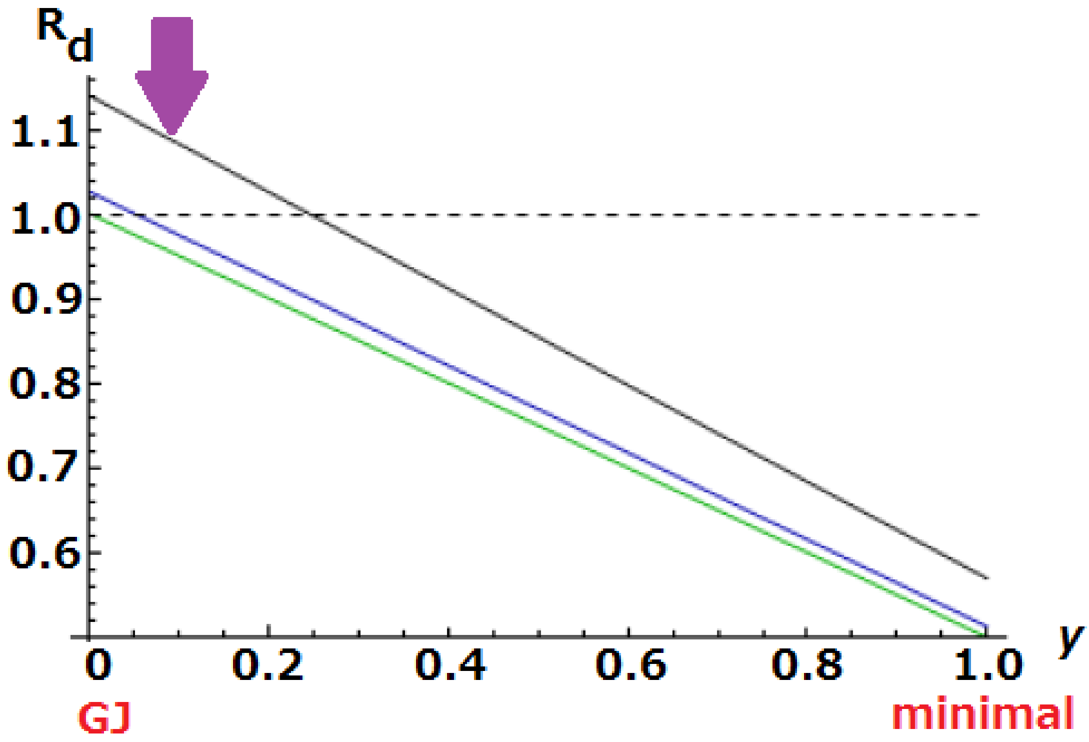
Drift direction I

- Consider $R_d = \omega_{mag/}\,\omega_E$
  - rotation state, y = 0.4 -> $R_d = 0.9 < 1$



Drift direction II

- Consider $R_d = \omega_{mag/}\ \omega_E$
  - rotation state, y = 0.1 -> $R_d = 1.1 > 1$
  - same drift rate but **opposite** in direction.



Stability in pulsar magnetosphere

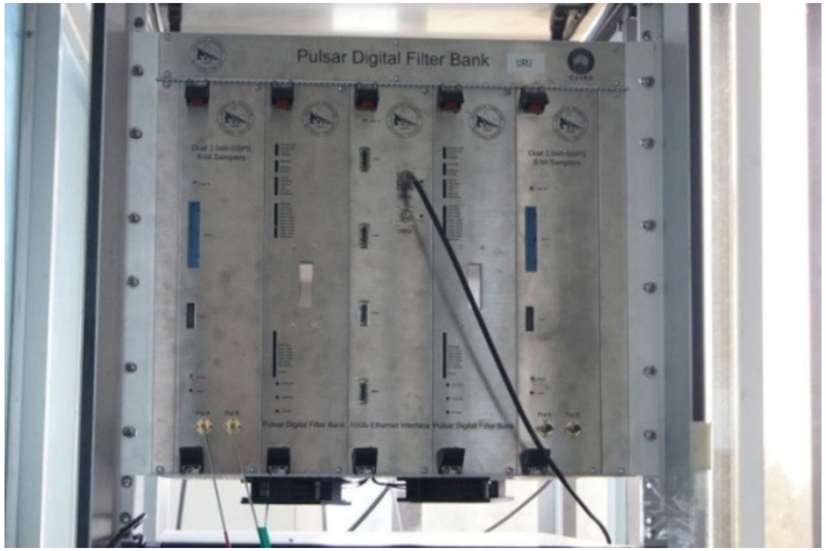
- Pulsar magnetospheres exist in different rotation states, *y*.
  - Can switch between different *y*.
  - Observations suggest that y
    - is time-dependent
    - changes rapidly.
- Stability of a magnetosphere is determined by *y*.
- A simple model that offers alternative explanation for varying drift rates.

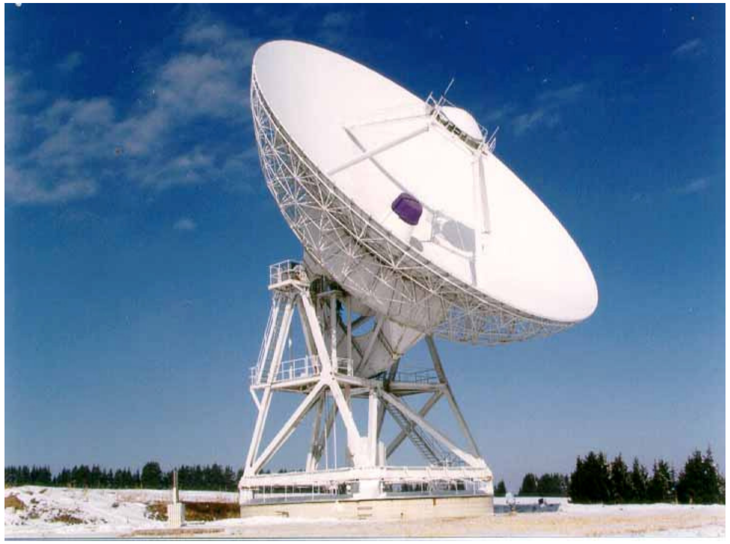
Planning ahead

- Primary goal: understand pulsar magnetospheres and their properties.
- Design observations based on the model
  - correlation between drift rates and observing frequencies.
  - changes in drift rates at one frequency.
  - stability in magnetosphere as modeled by y.

Measuring small effects

- Using 25 meter radio telescope at Nanshan, Urumqi.
  - Analog and digital filter bank.
  - Currently, the telescope is under upgrade for a better system, e.g., shorten the receiver change-over time.





Conclusion

- A model for drifting subpulses.
- Can design observations for the 25 m telescope.
- Small effects, single-pulse events.
- A Larger telescope with higher resolution and sensitivity is desirable

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