Estimating the evolution of Sparks in Partially Screened Gap of Pulsars from Subpulse Drifting

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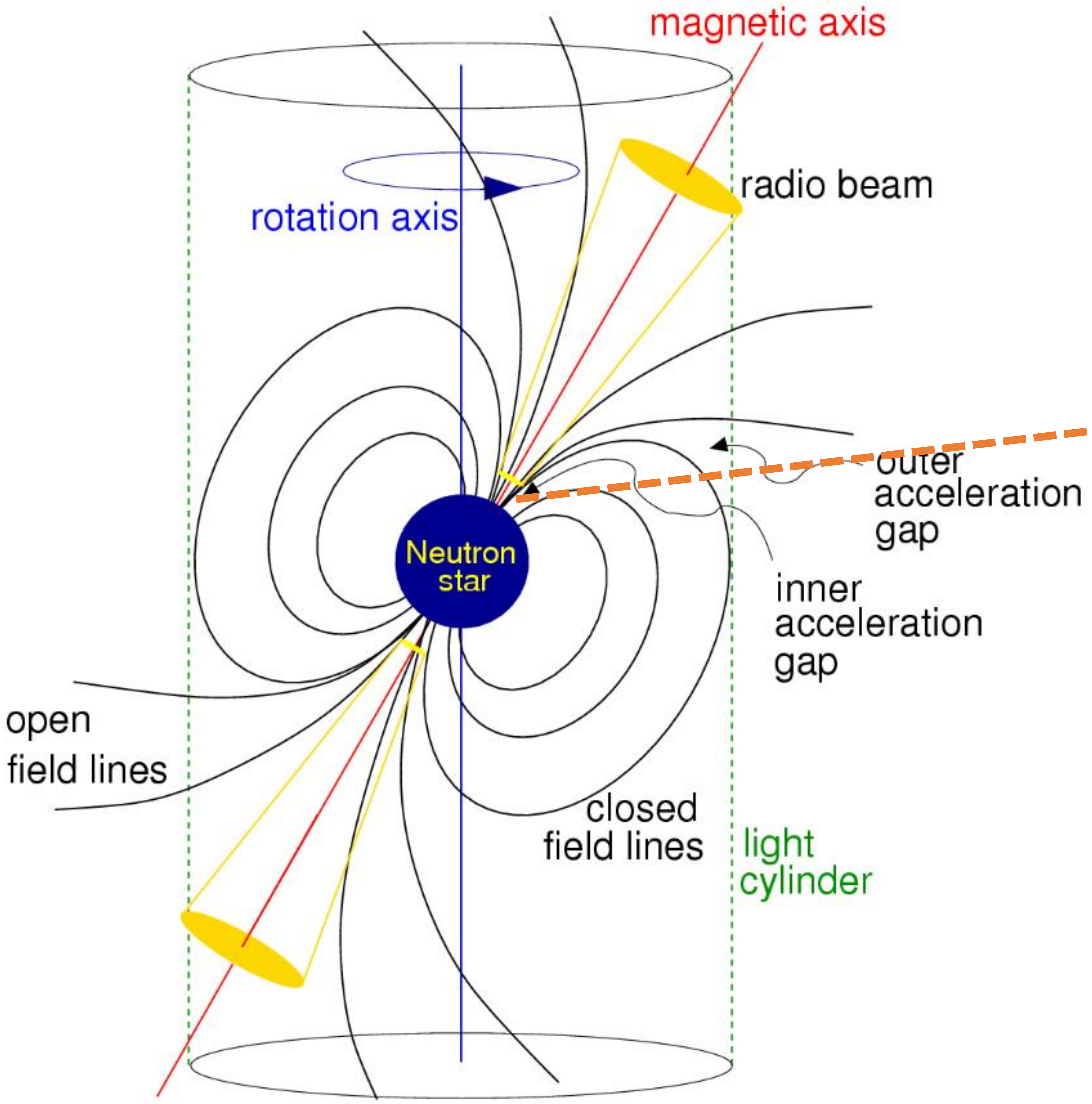

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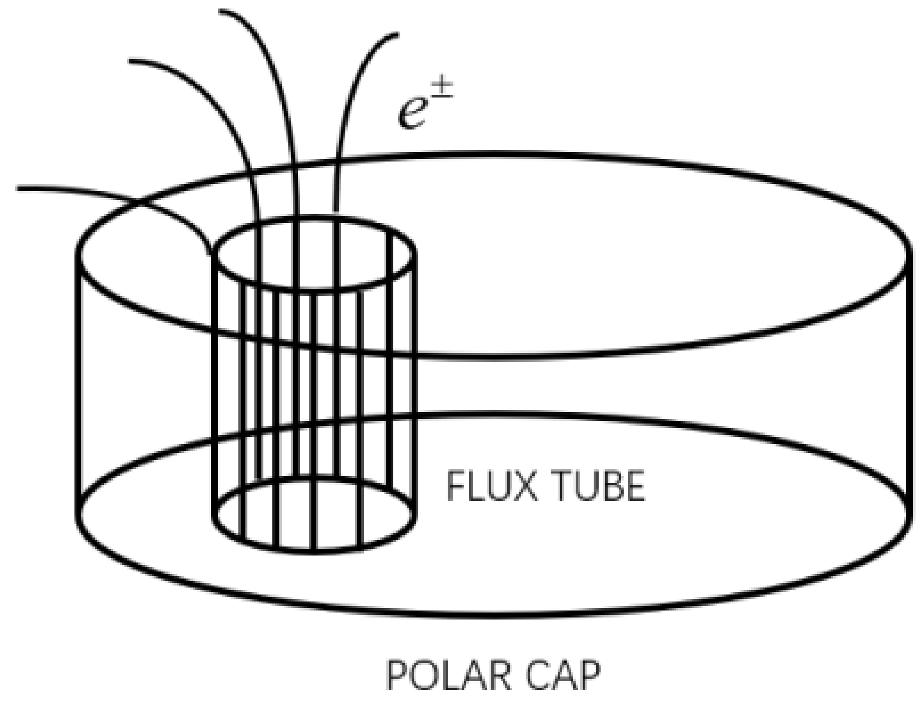
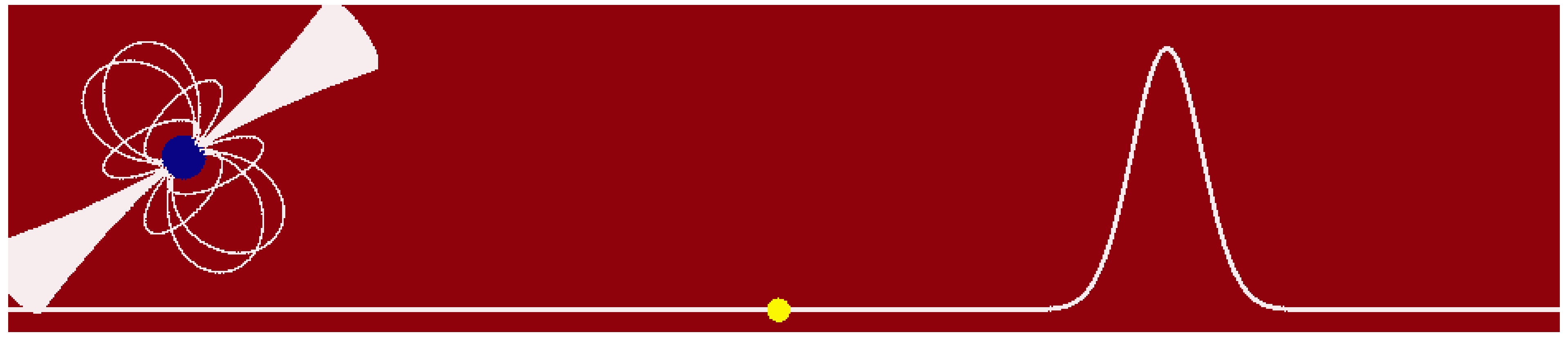
Theories predict that there exists places **where E·B≠0** (such as vacuum gaps), at which a series of particle processes happen.



The paper considers
inner acceleration gap
or inner acceleration region (IAR).



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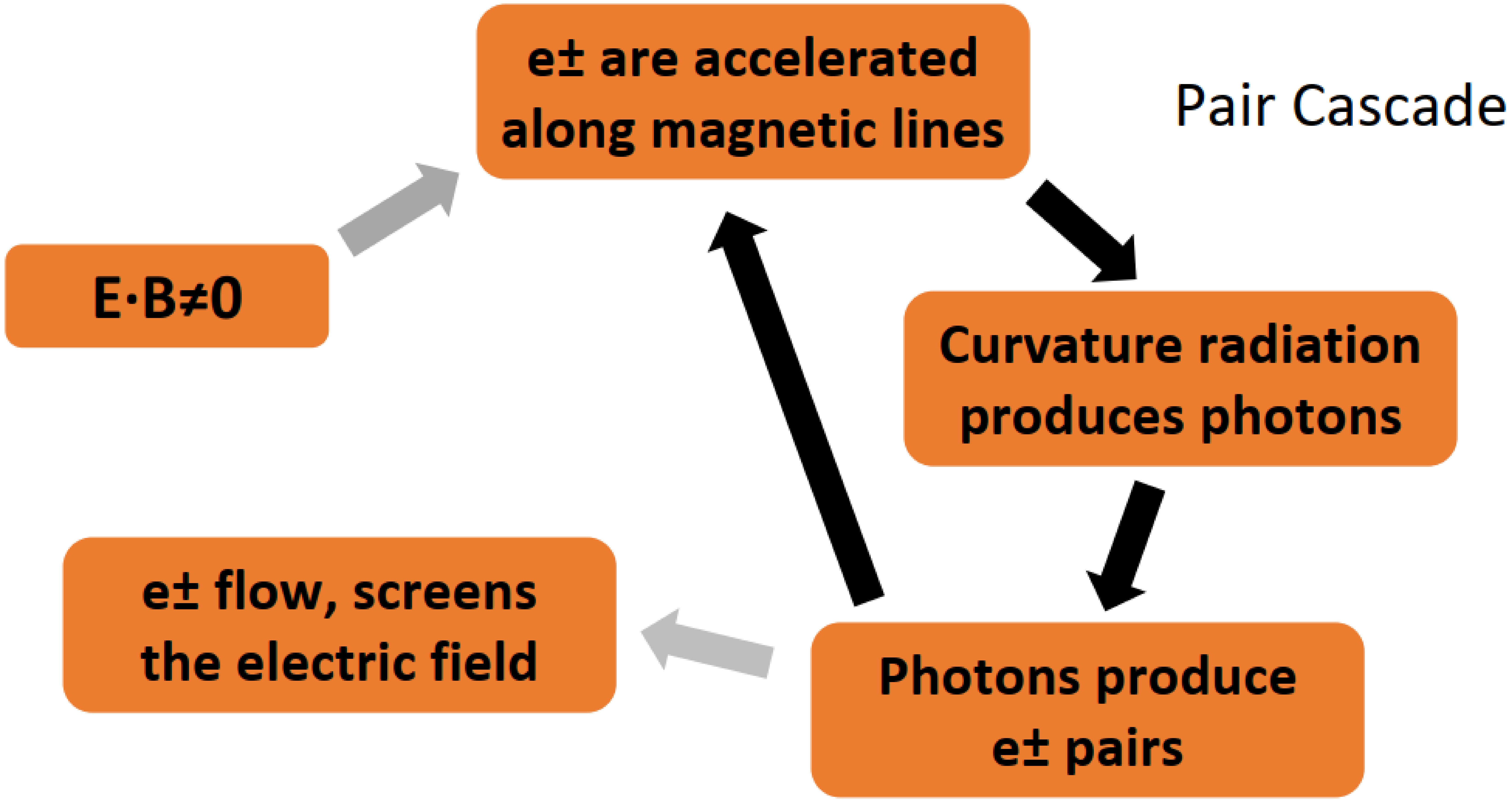
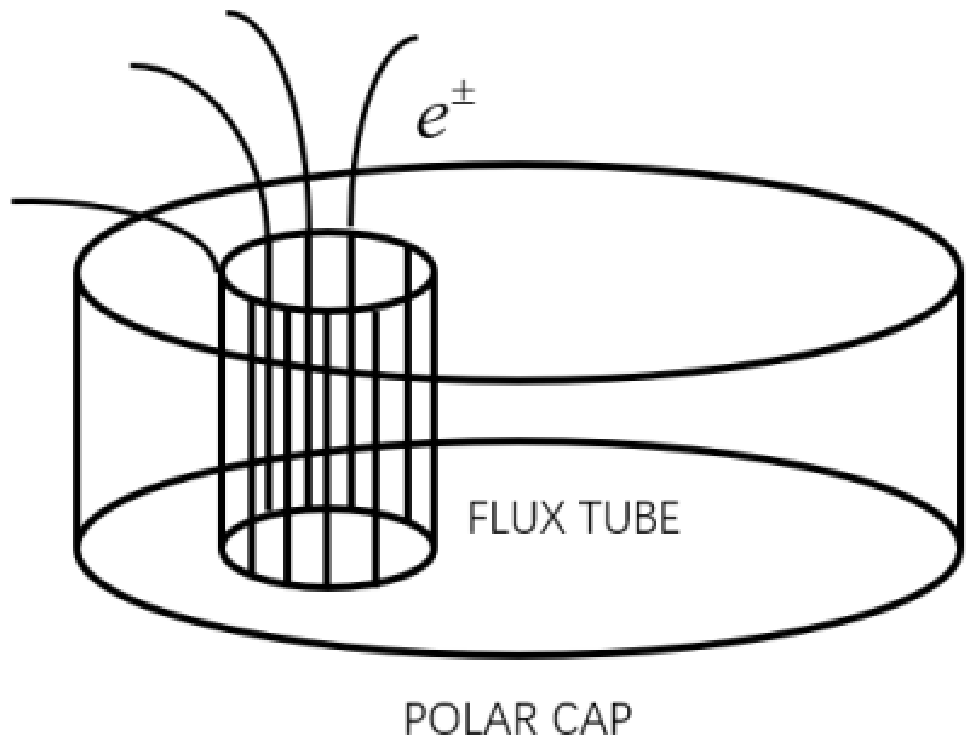
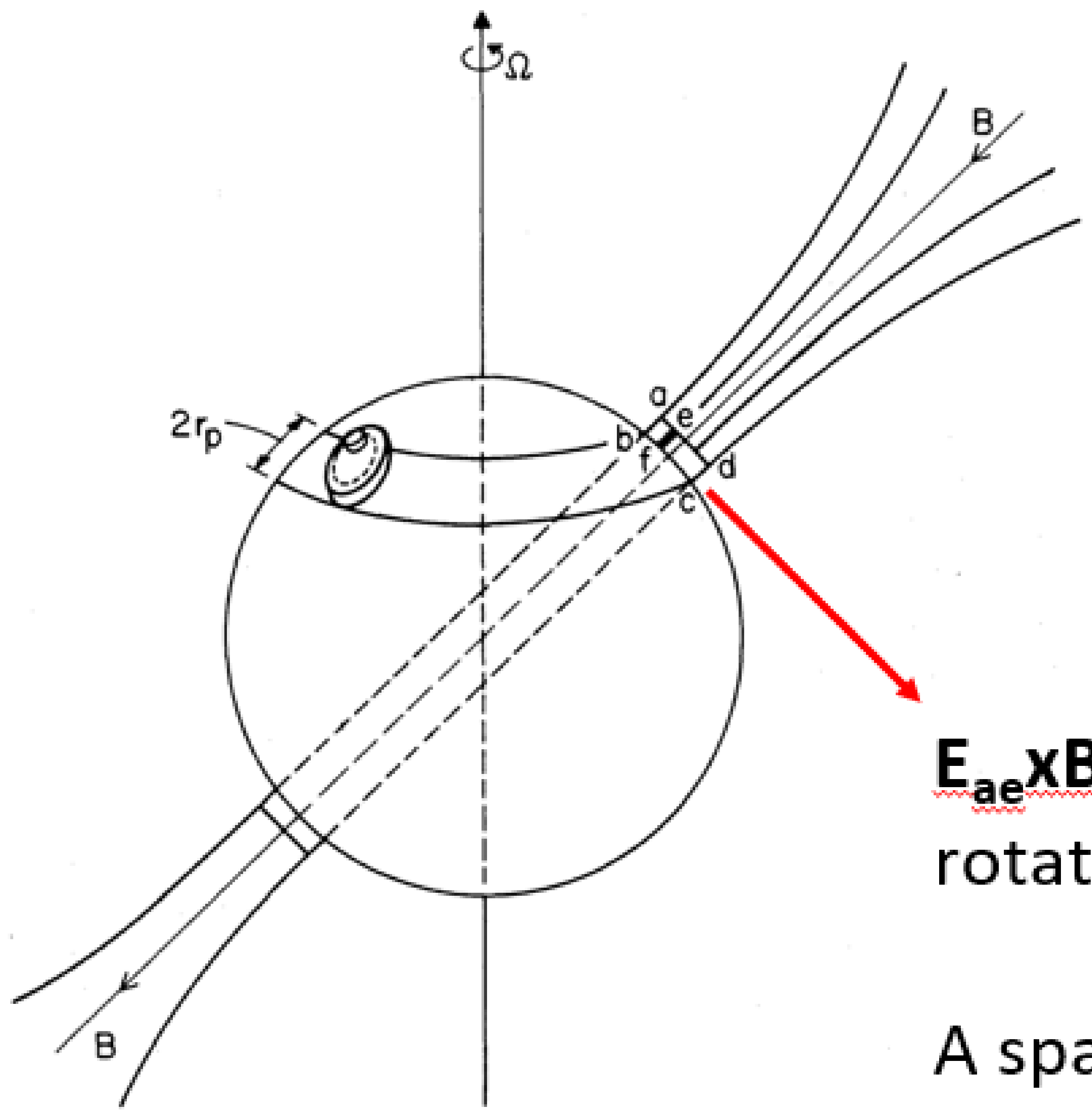
Particle acceleration and plasma's formation:
Take pure vacuum gap (like RS 75) for example:



Bunches of electrons/positrons flow out of vacuum gap,
produce coherent radio radiation……

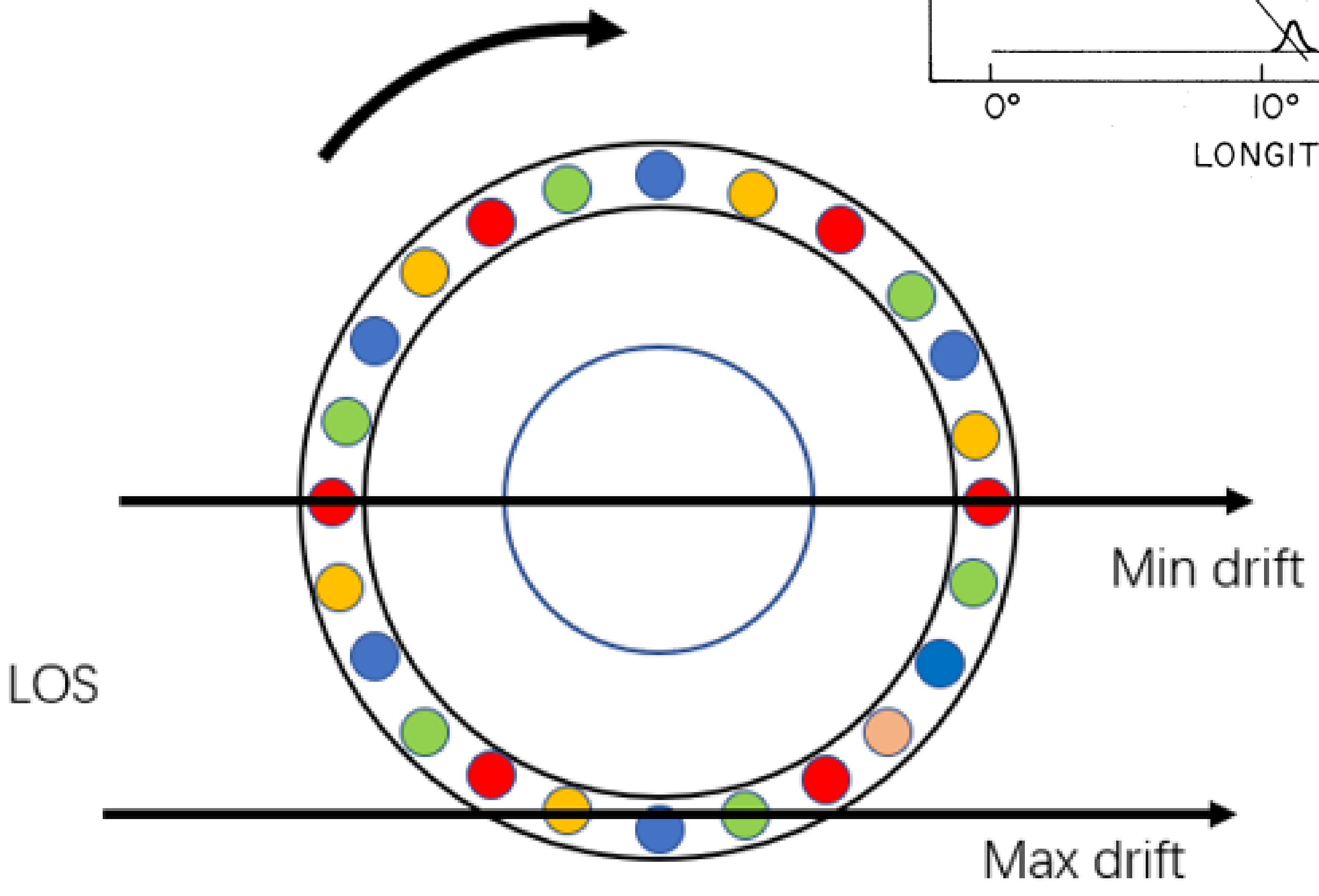
pure vacuum gap ➔➔➔ sub-pulse drifting:

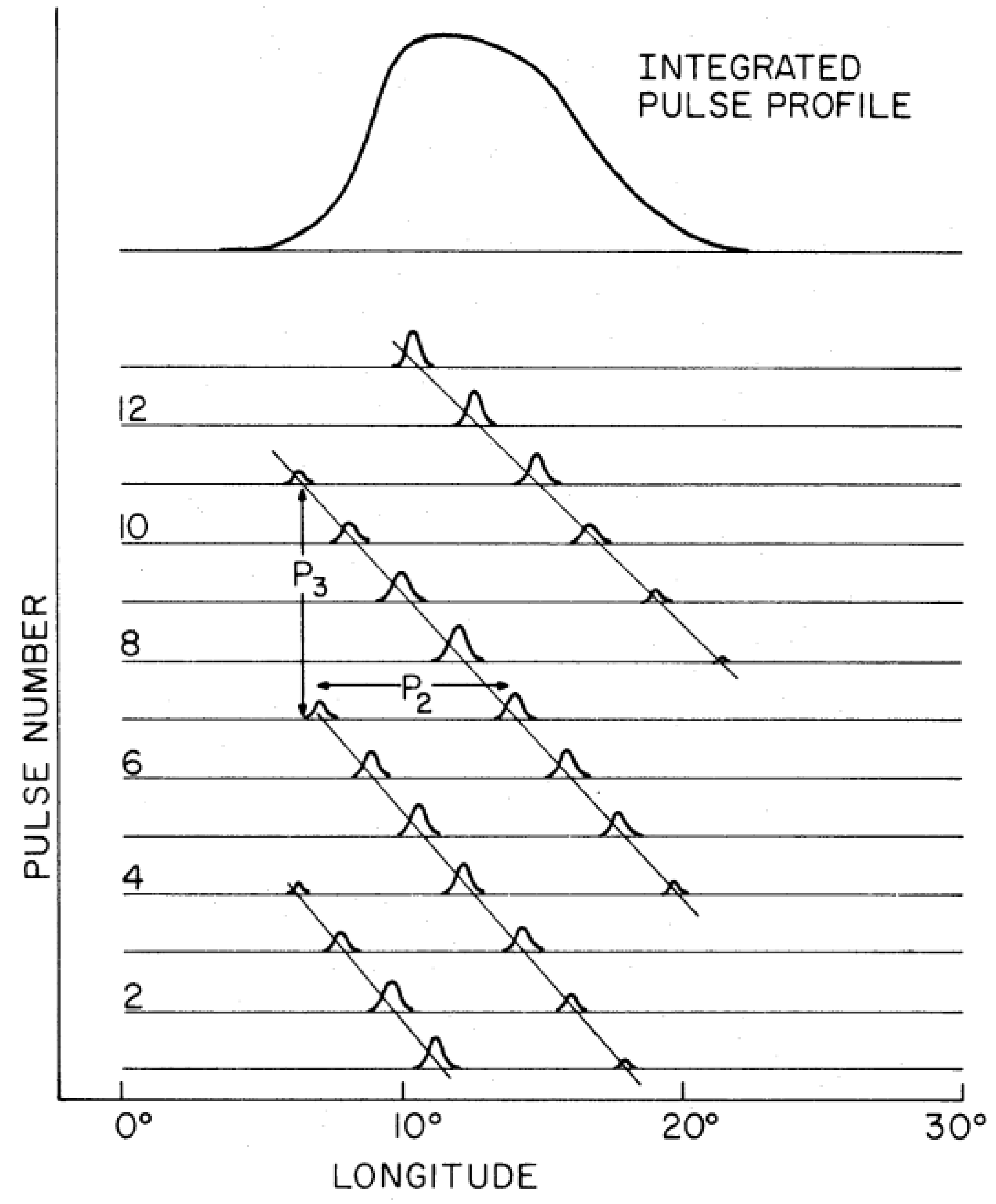




E_{ae}xB makes sparks rotate. Period **P_d**.

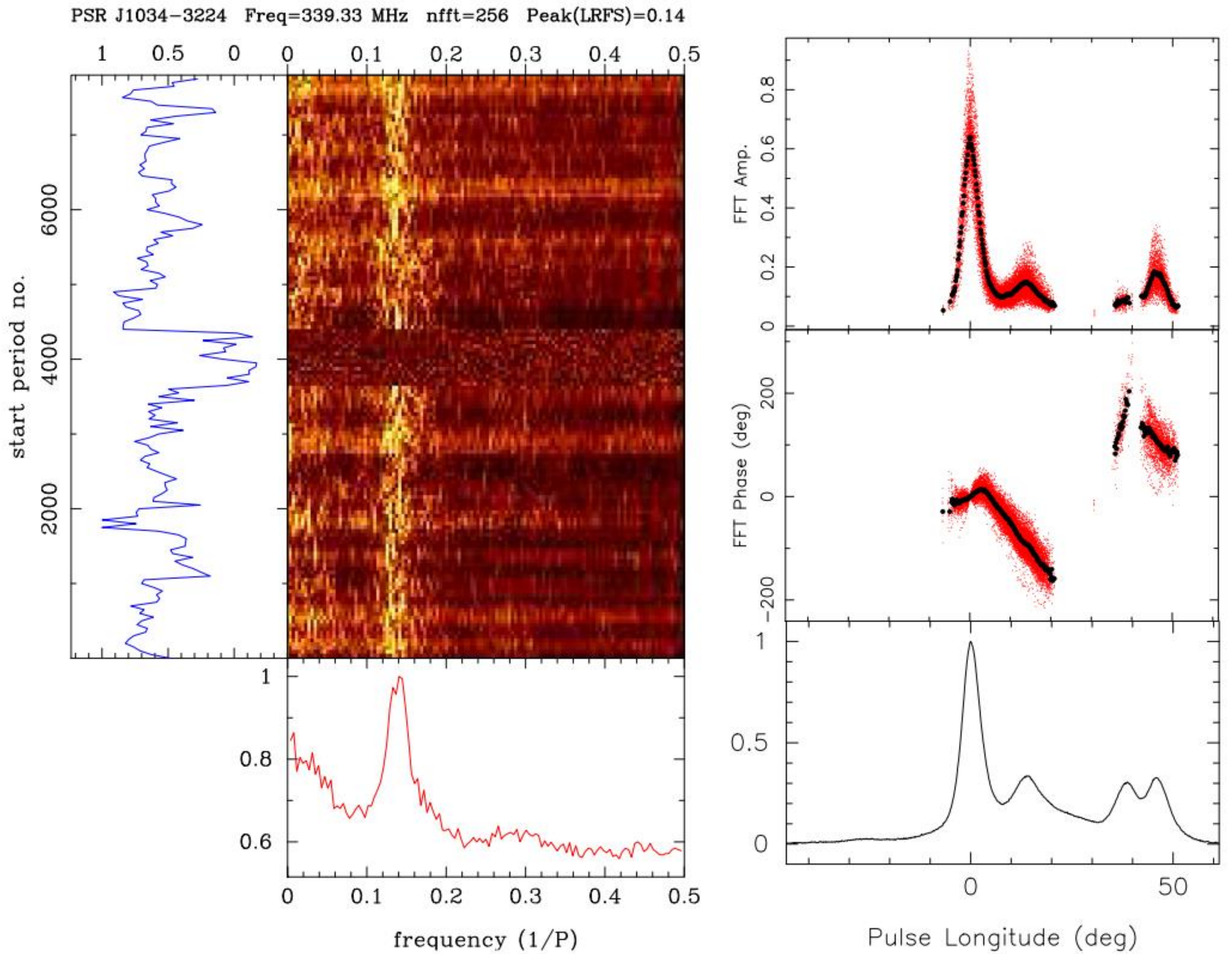
A spark ⇔ A sub-pulse





From Ruderman & Sutherland 1975

Challenges: more complex drifting phenomena (bi-drifting…) (and drifting speed, binding energy…)



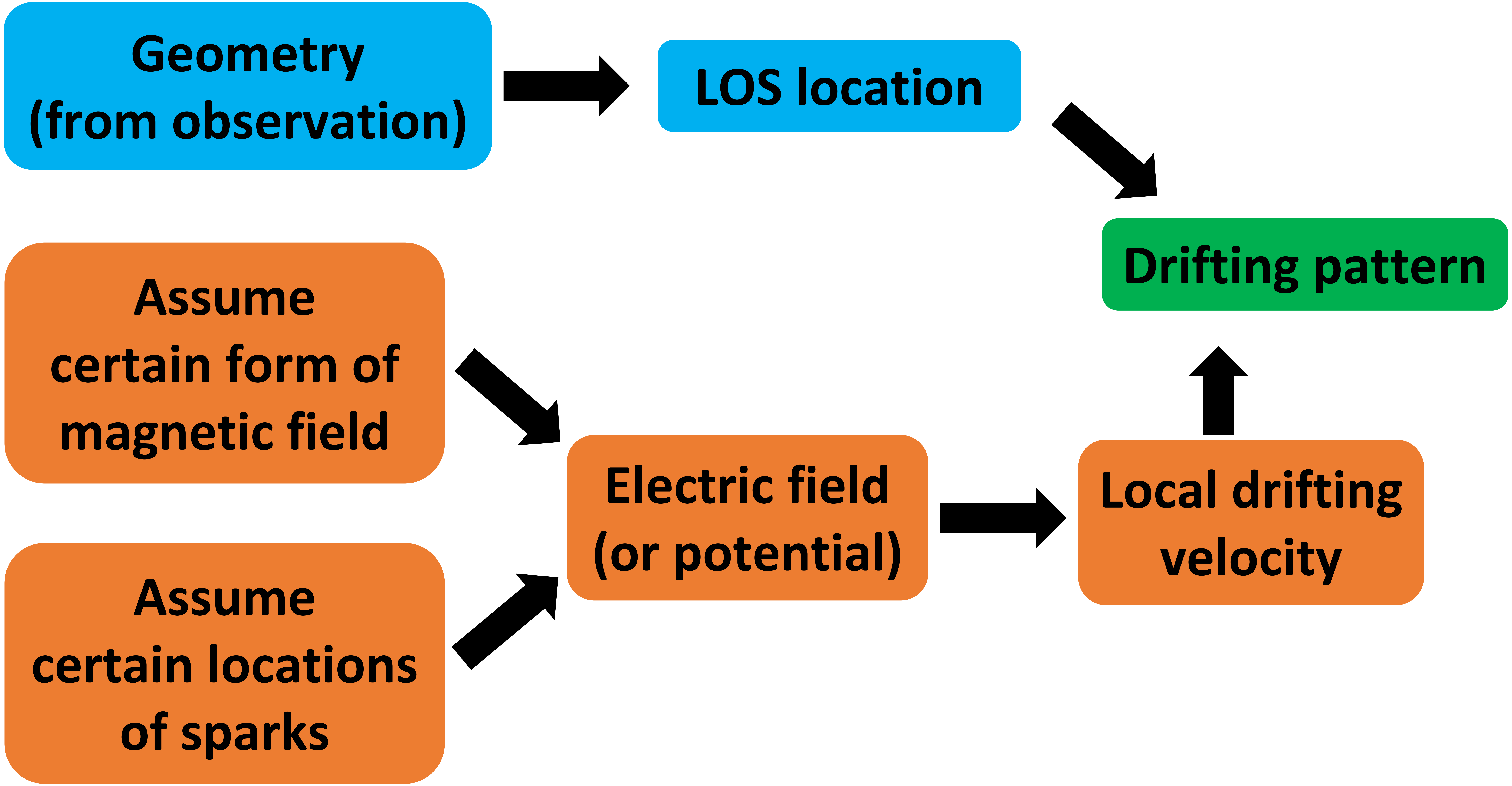
Basu & Mitra (2018)

Gil, Melikidze and Geppert 2003: Partially Screened Gap (PSG) model.

· Non-dipole magnetic field near pulsar surface.
· Positive ions continuously flow out.

➔➔➔ ExB variable (drifting is locally decided).

Way to figure out magnetic field (polar cap) structure:



II. Geometry measurement

Observation: J1034-3224 and J1720-2933, GMRT

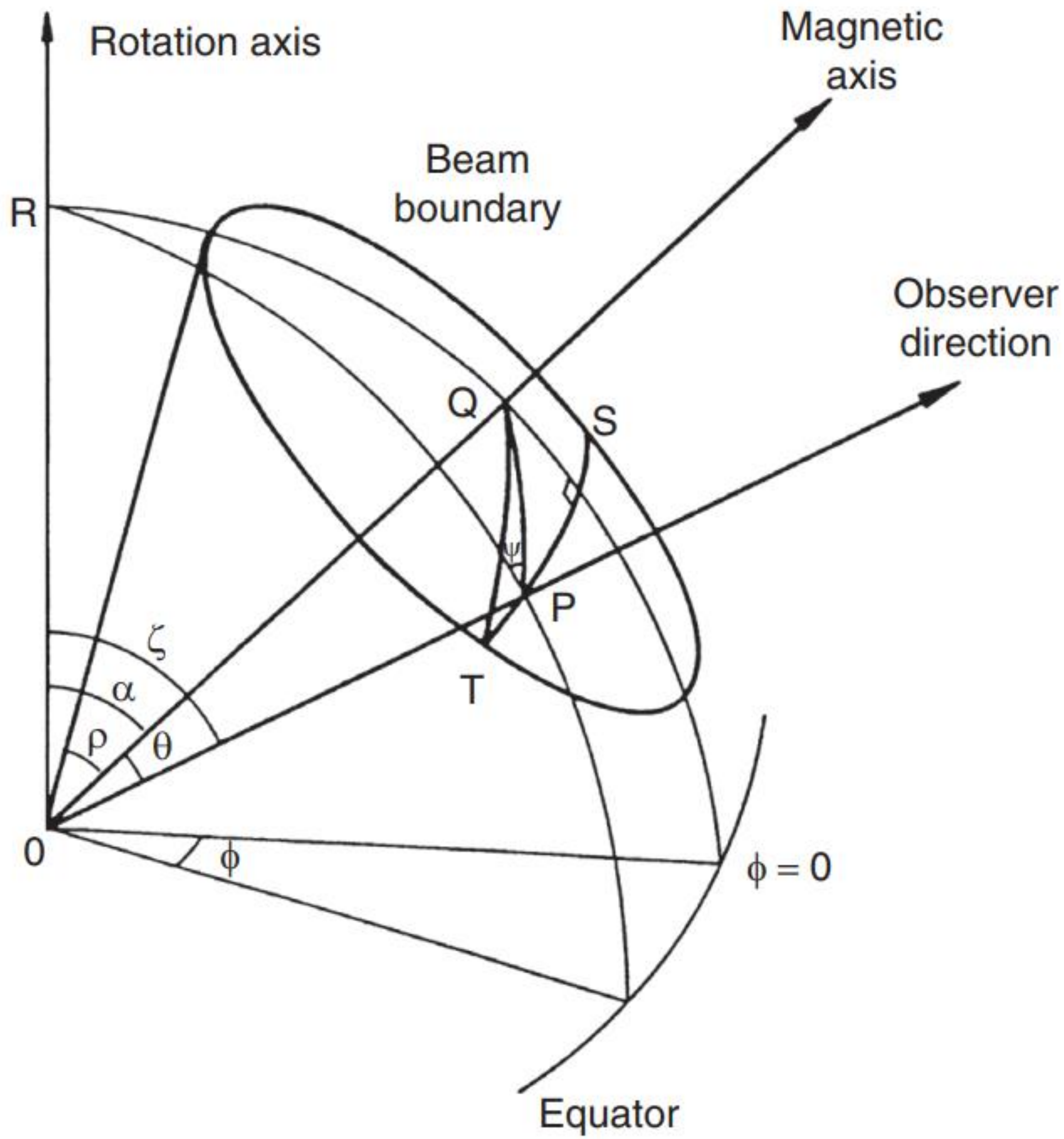
PSR	P (s)	$\dot{P}$ ($s\ s^{-1}$)	ν (MHz)	W_C (°)	$W_{5\sigma}$ (°)	W_B (°)	R_{ppa} (°)	α (°)	α_m (°)	β (°)	ρ (°)	S_{los}	h (km)
1034−3224	1.15	2.3×10^{-16}	325	7.4±0.9	80.2±1.8	2.37	9.95	17.4±2.0	16.6/163.4	±1.6	11.9	±0.14	1073
			610	7.1±0.2	68.9±0.4	2.16		16.5±0.5			10.3	±0.16	806
J1720−2933	0.62	7.5×10^{-16}	325	5.0±0.2	25.7±0.4	2.37	-6.6	37.1±1.7	38.3/141.7	±5.4	9.2	±0.59	348
			610	4.2±0.2	24.1±0.4	2.16		40.3±2.3			8.8	±0.61	320

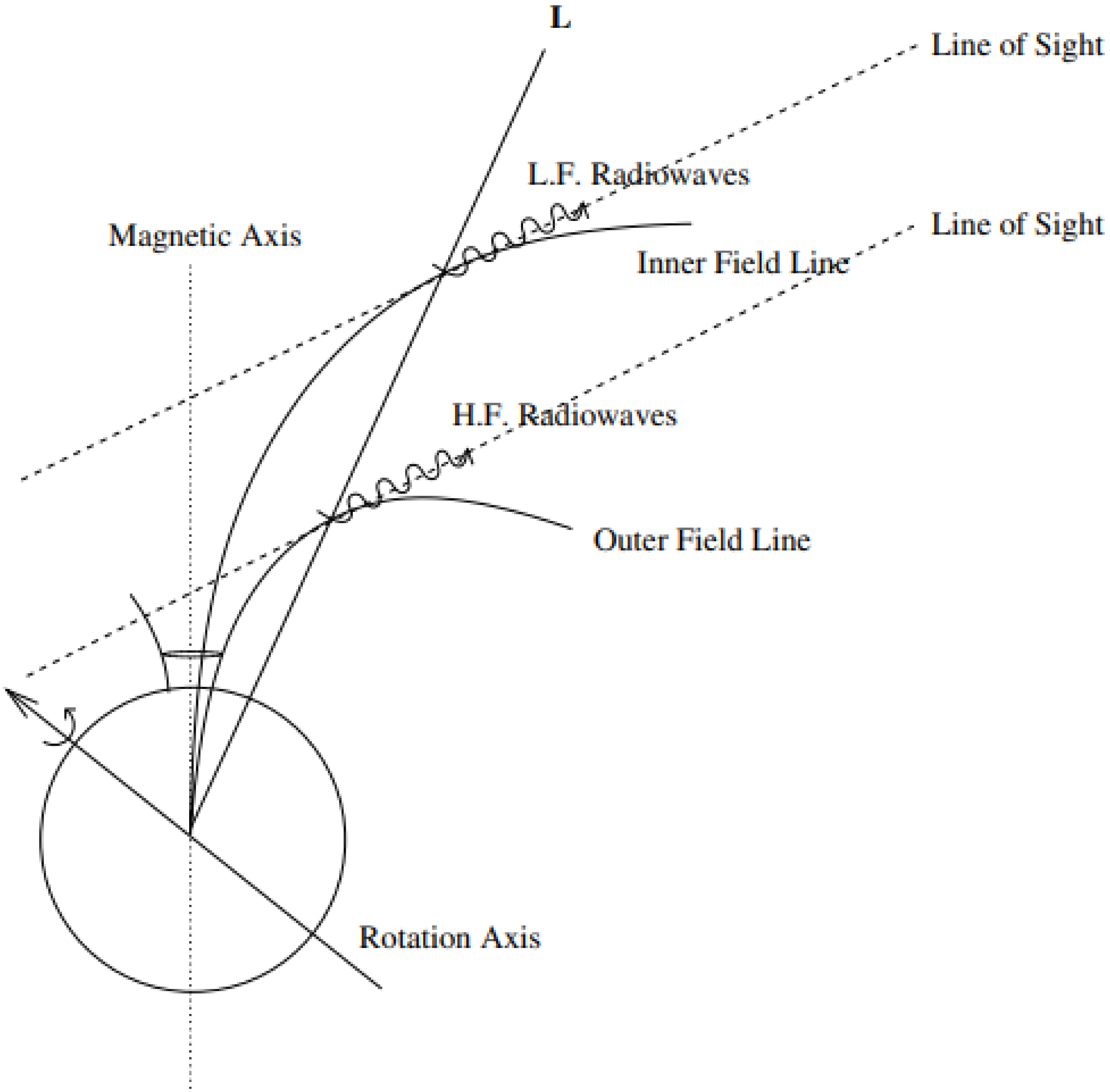
Profile half width (from Mitra et al. 2016): $$W_C = W_B P^{-0.5} / \sin\alpha$$

PPA steepest gradient: $$R_{ppa} = |\sin\alpha / \sin\beta|$$

Beam angle: $$\sin^2(\rho_\nu/2) = \sin\alpha \sin(\alpha+\beta) \sin^2(W_{5\sigma}/4) + \sin^2(\beta/2)$$

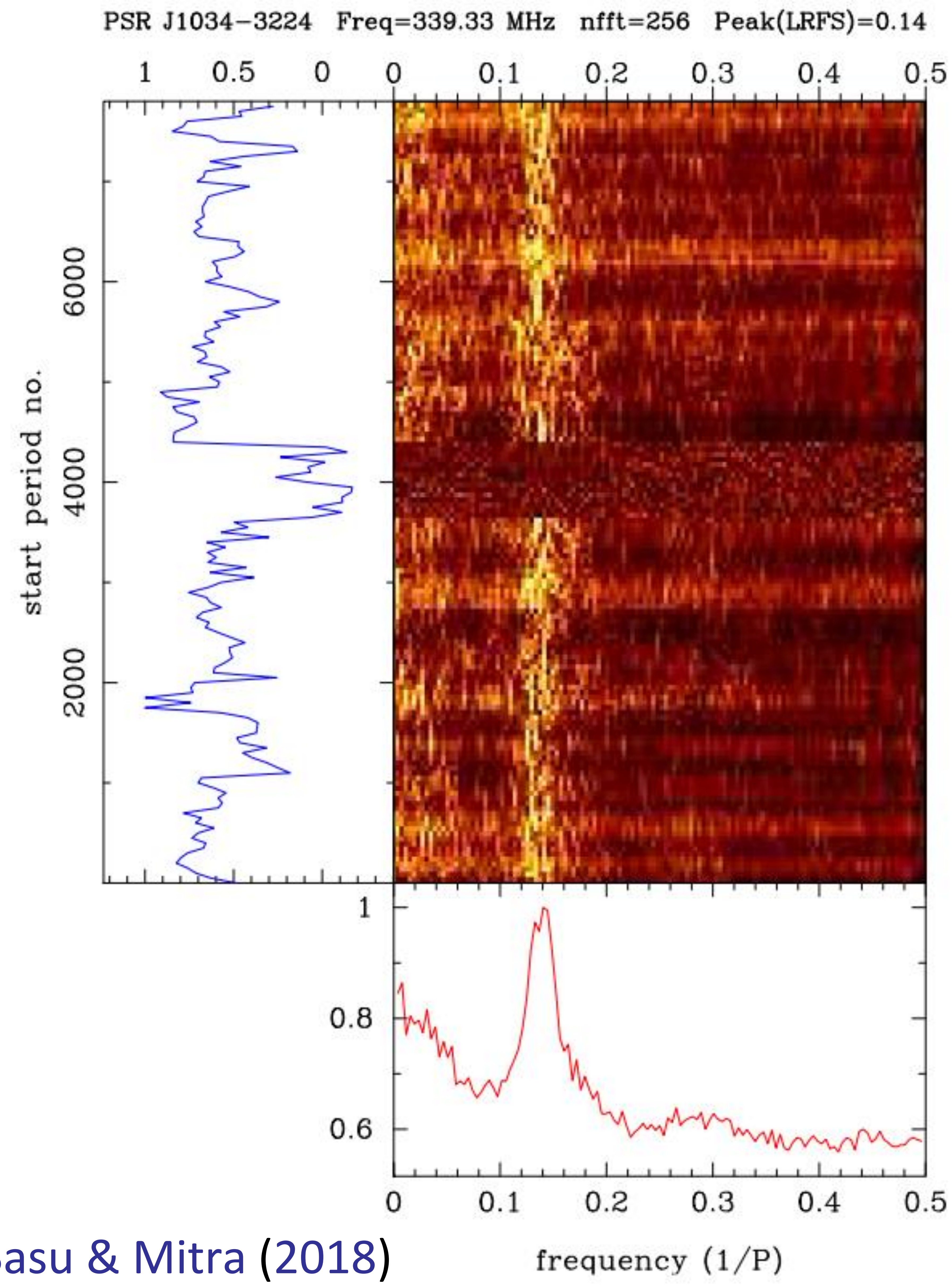
Emission height: $$h_\nu = 10P\left(\frac{\rho_\nu}{1.23^\circ}\right)^2 \text{km}$$



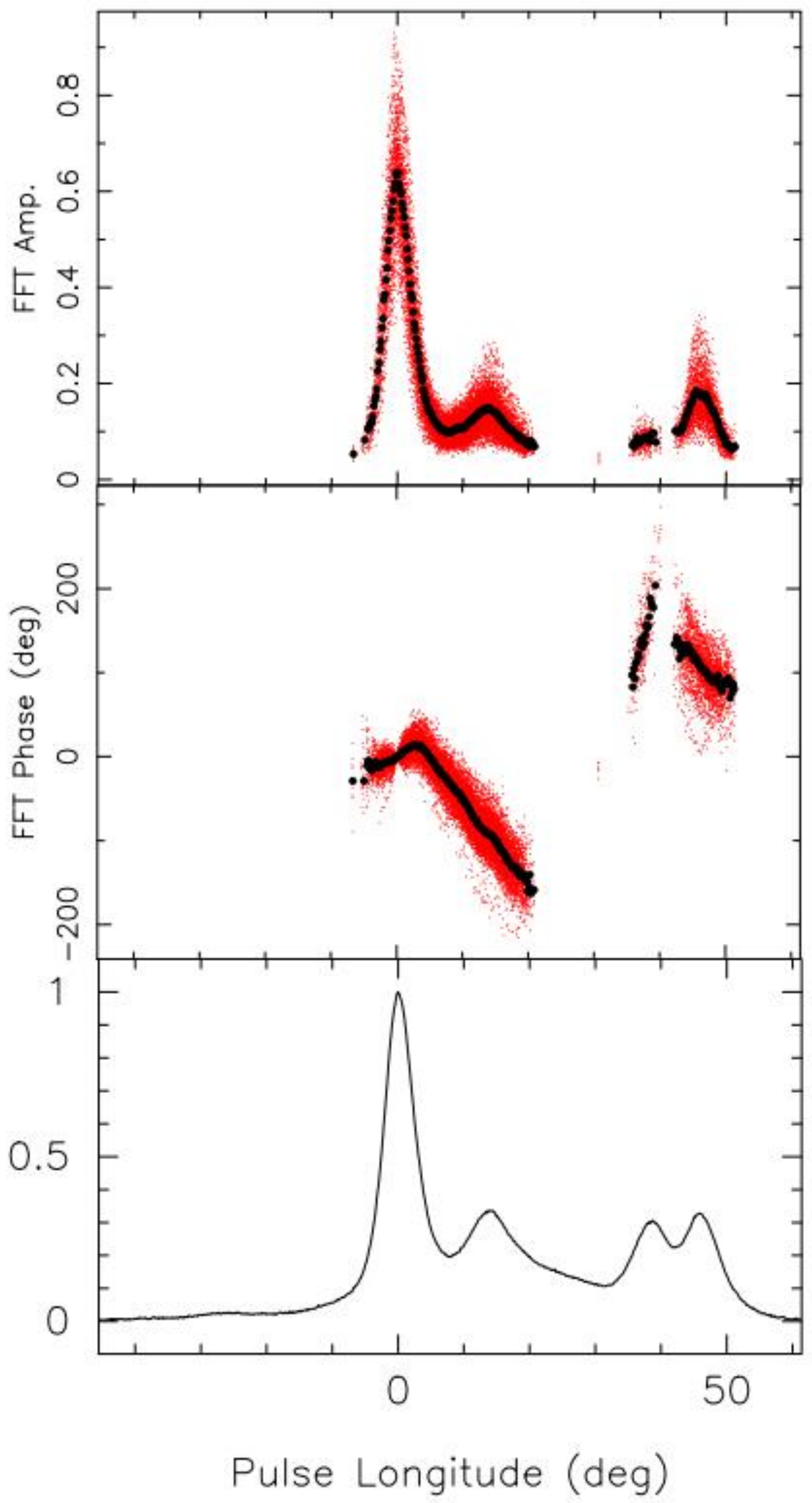


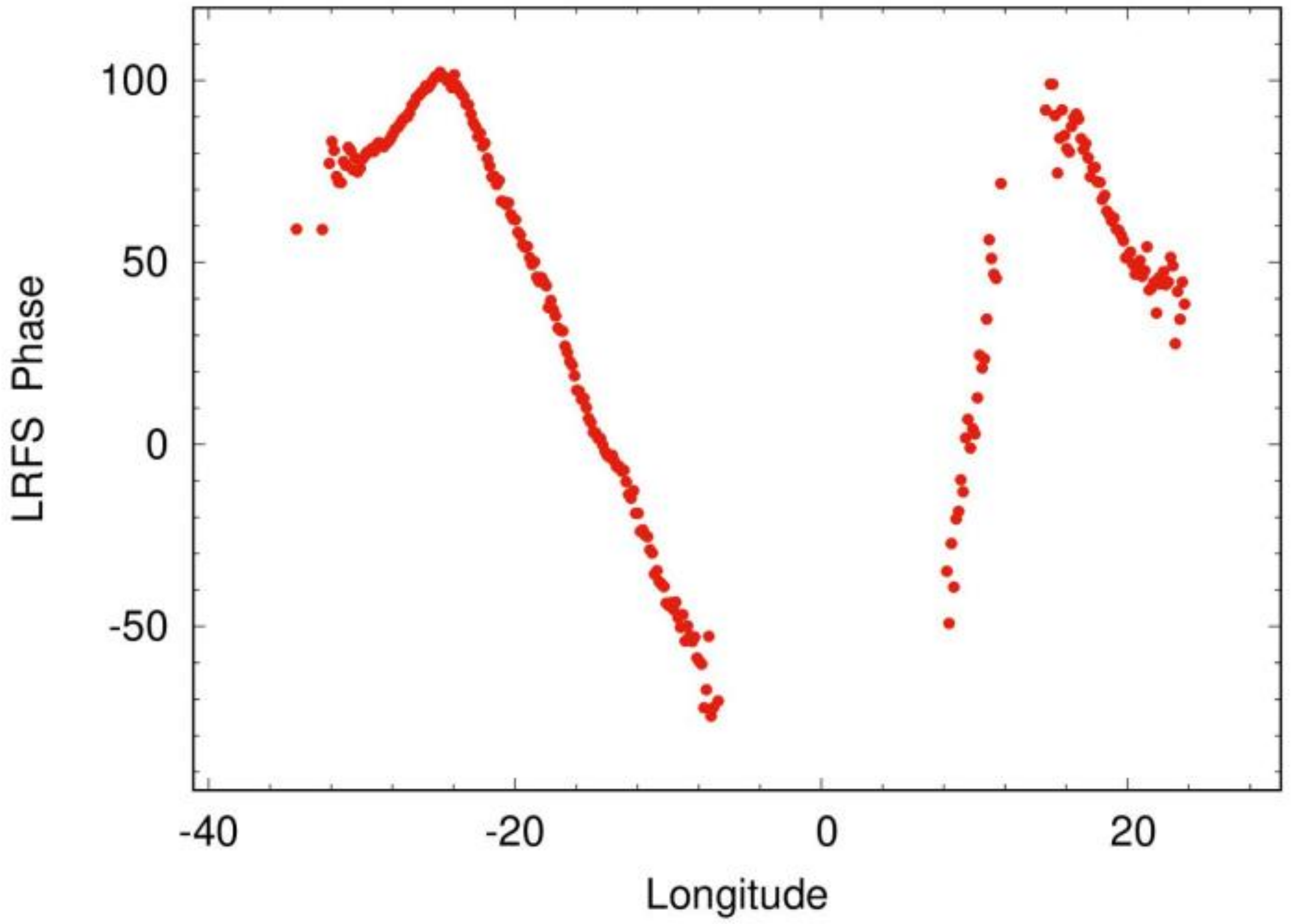
et al. (2016), and we carried out RVM fits to obtain R_{ppa} for each pulsar (the detailed RVM fitting process for the pulsars in the MSPES survey, including the two reported here, is shown in Mitra et al. 2023, in preparation). The α

Drifting properties for J1034-3224:



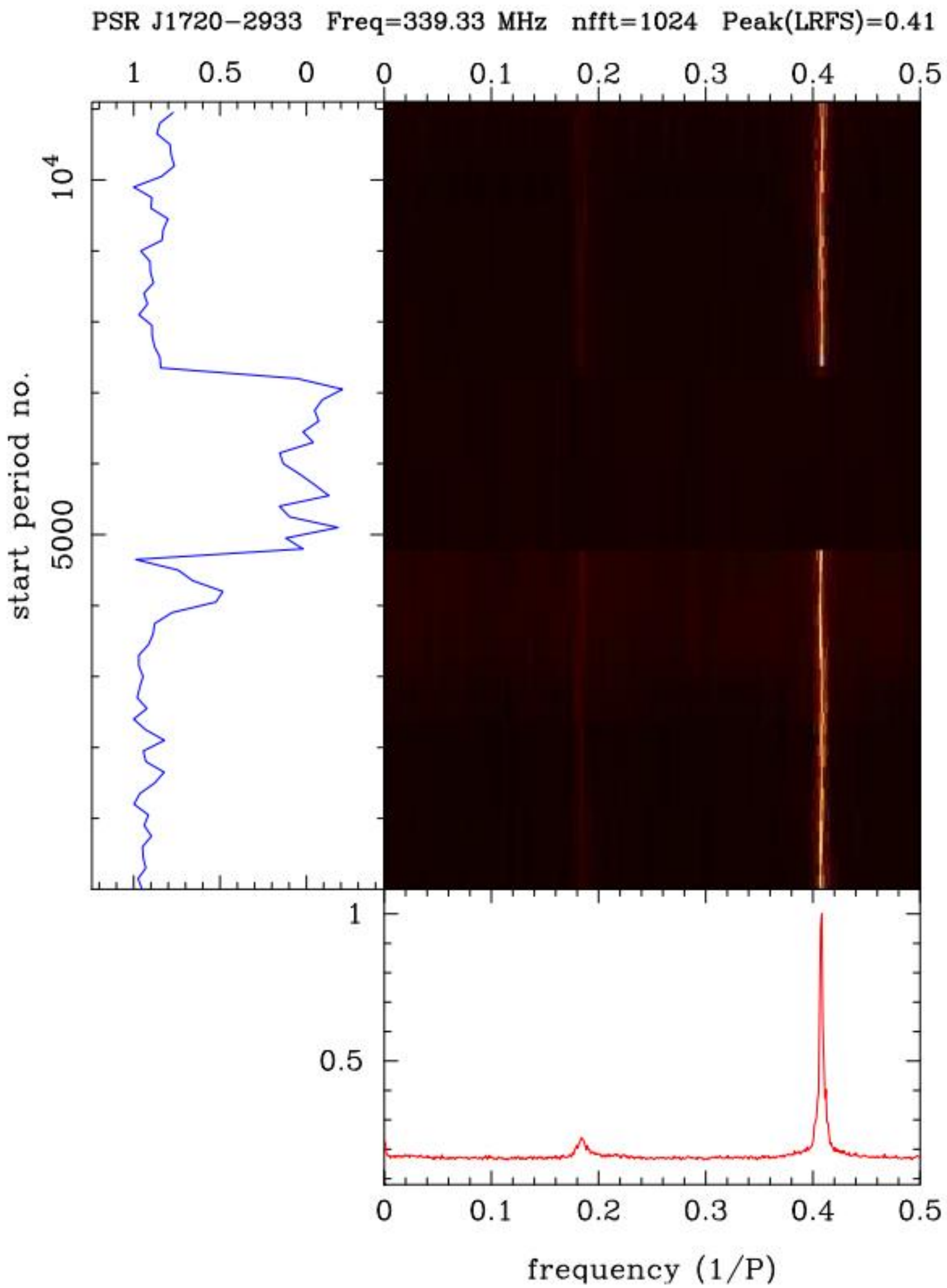
Basu & Mitra (2018)

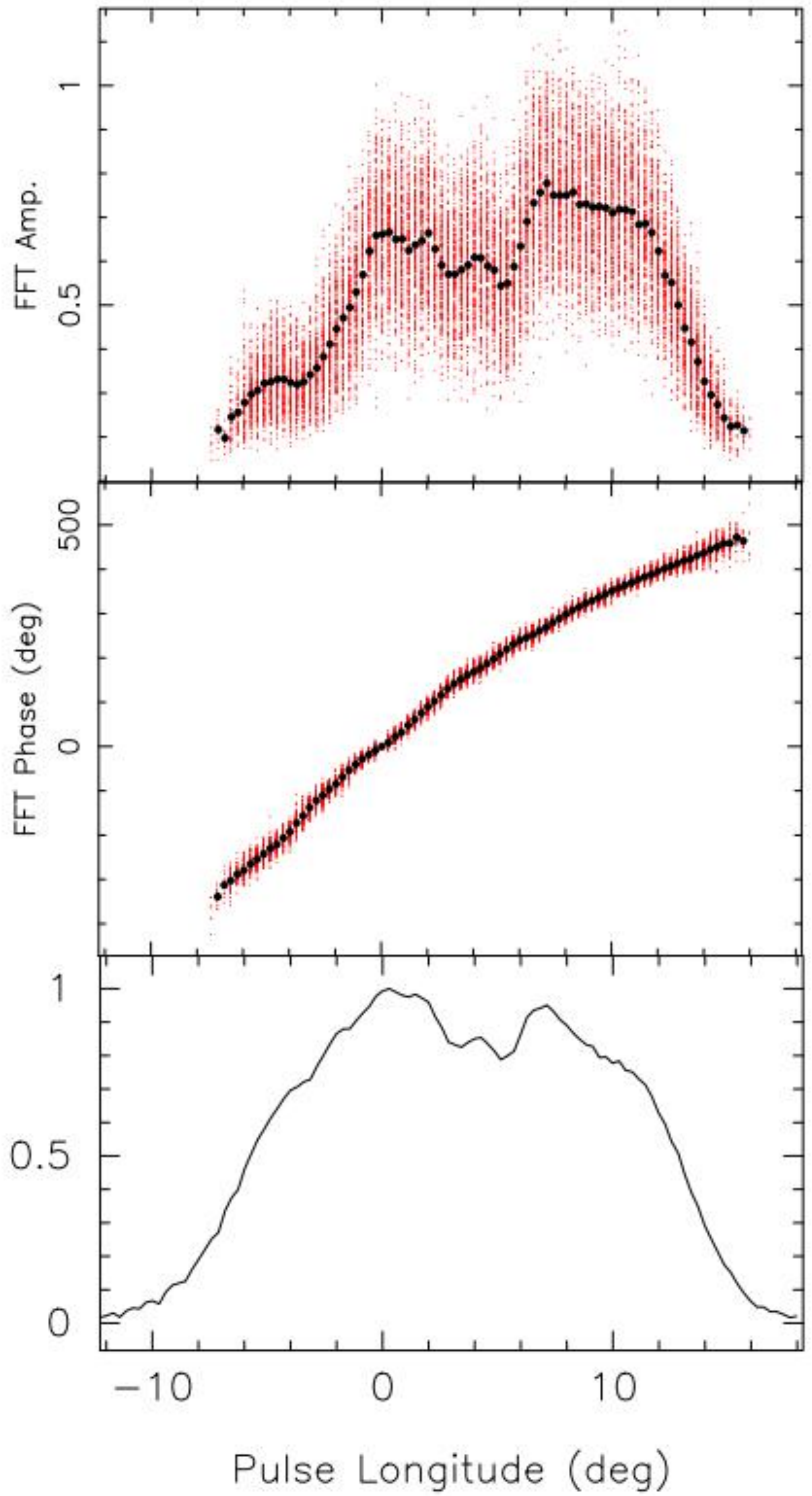


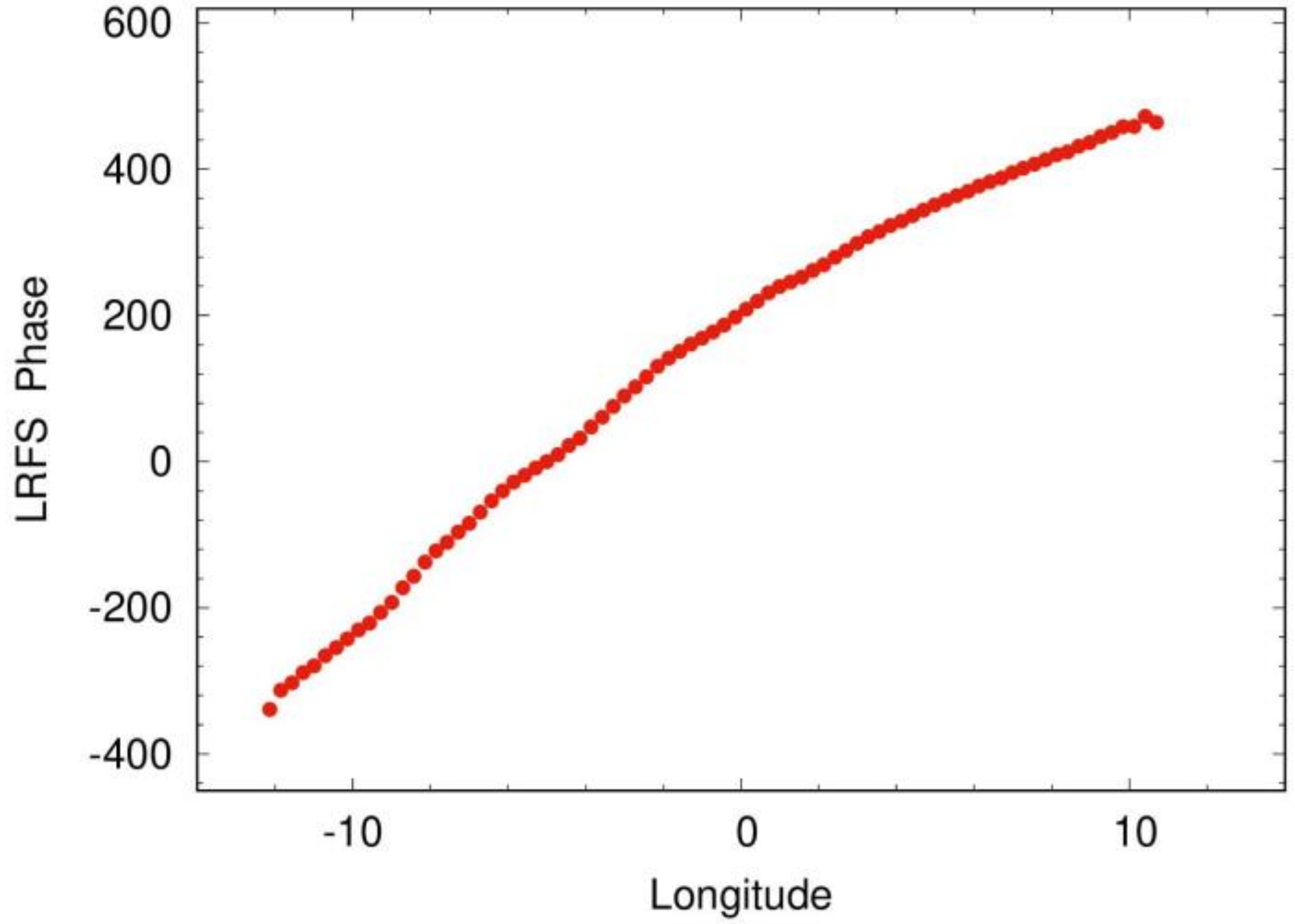


This paper

Drifting properties for J1720-2933:







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Basu & Mitra (2018)

III. Model related to observation

$$d = B_d R_S^3,\ B_d = 10^{12}(P\dot{P}_{-15})^{0.5}\ \mathrm{G}$$

Magnetic field settings:

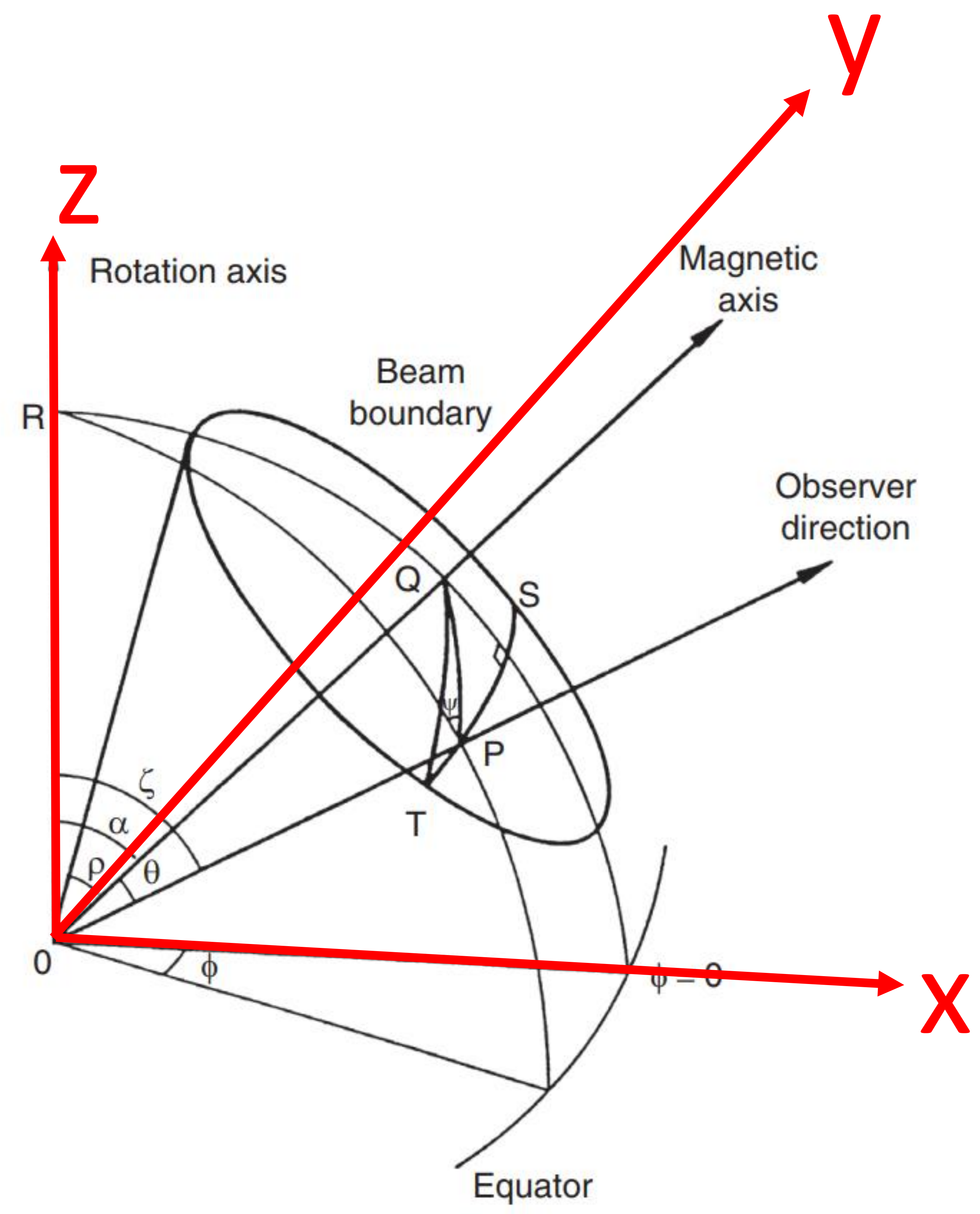
Non-dipole field

←→ A star centered dipole field (x-z plane) $\boldsymbol{d} = (d, \theta_d, 0°)$ (α → θ_d)

\+ some weaker dipole fields on star surface

$$\boldsymbol{m}_i = (m^i, \theta_m^i, \phi_m^i) \qquad \boldsymbol{r}_i = (r_s^i, \theta_s^i, \phi_s^i)$$

$$m = 0.01d \qquad r_s = 0.95R_S$$



Polar cap located at: $(R_S, \theta_{cap}^c, \phi_{cap}^c)$ $R_S = 10^6$ cm

Polar cap and sparks: elliptical, major axis **a**, minor axis **b**

Effective size of sparks: $h_\perp \sim \sqrt{a_{sprk} b_{sprk}}$

Potential difference in the gap:

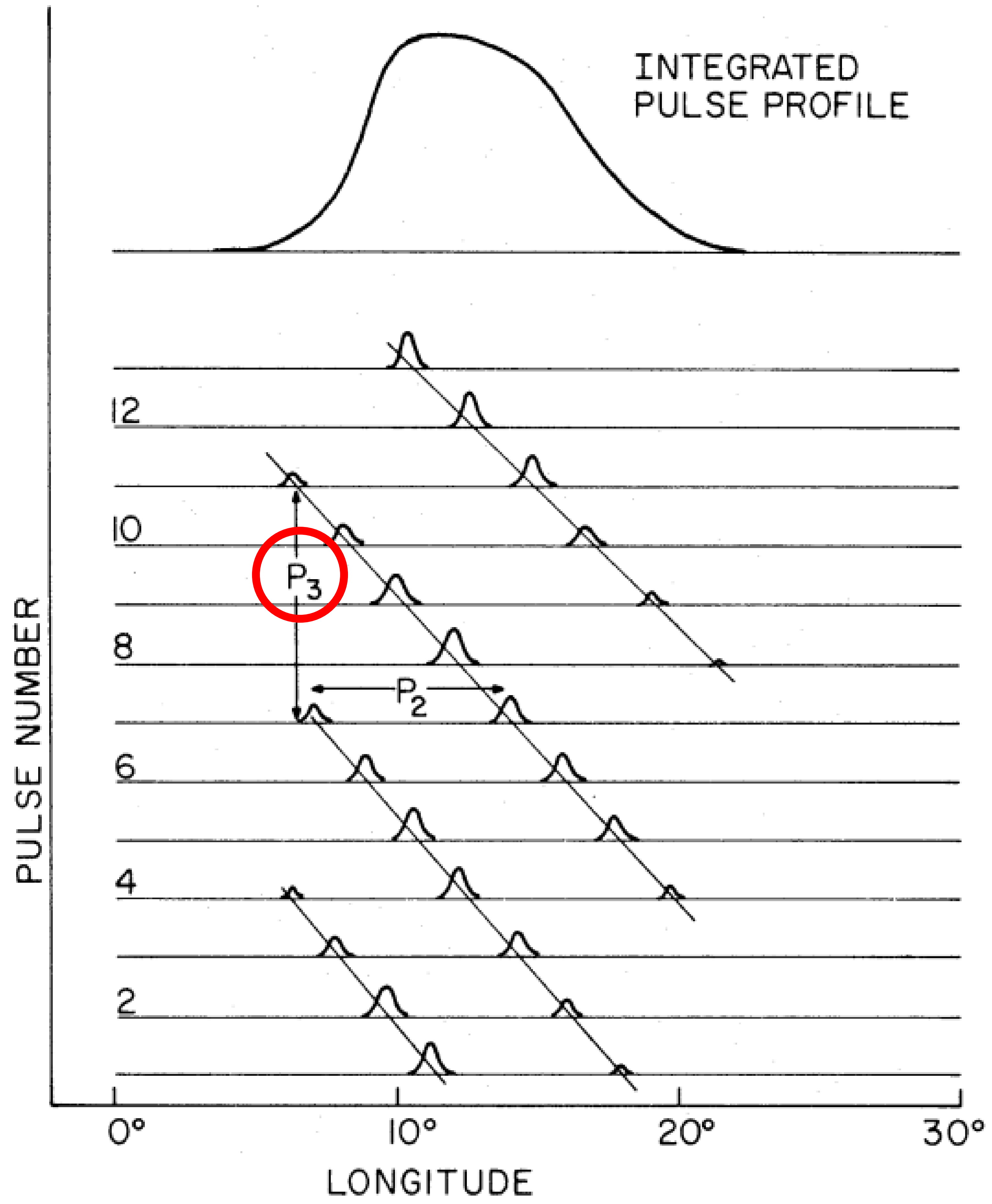
Non-dipole/Dipole

$$\Delta V_{PSG} = \frac{4\pi\eta b B_d |\cos\alpha_l|}{Pc} h_\perp^2 \qquad b = B_s/B_d$$

Screening factor: $\eta = 1/(2\pi P_3|\cos\alpha_l|) = 1 - \rho_i/\rho_{\mathrm{GJ}}$

Polar cap temperature:

$$T_i = (\eta b)^{1/2} \, |\cos\alpha_l|^{1/4} \left(\frac{h_\perp}{2.6\mathrm{m}}\right)^{1/2} \left(\frac{\dot{P}_{-15}}{P}\right)^{1/4} \times 10^6 \;\; \mathrm{K}.$$



α_l, the angle made by the local non-dipolar magnetic field with the rotation axis

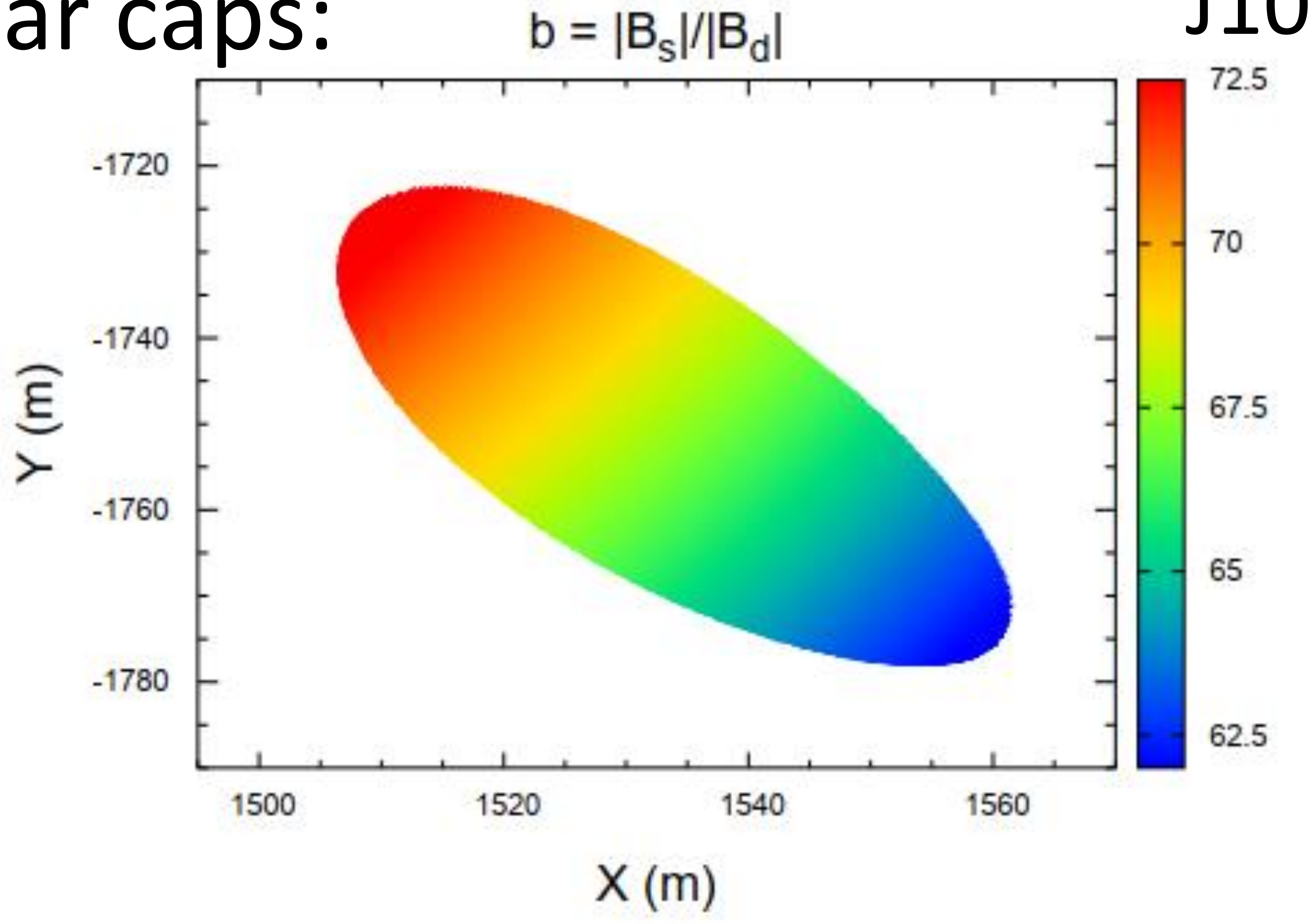
Numerical calculation results:

Table 2. The physical parameters of Partially Screened Gap

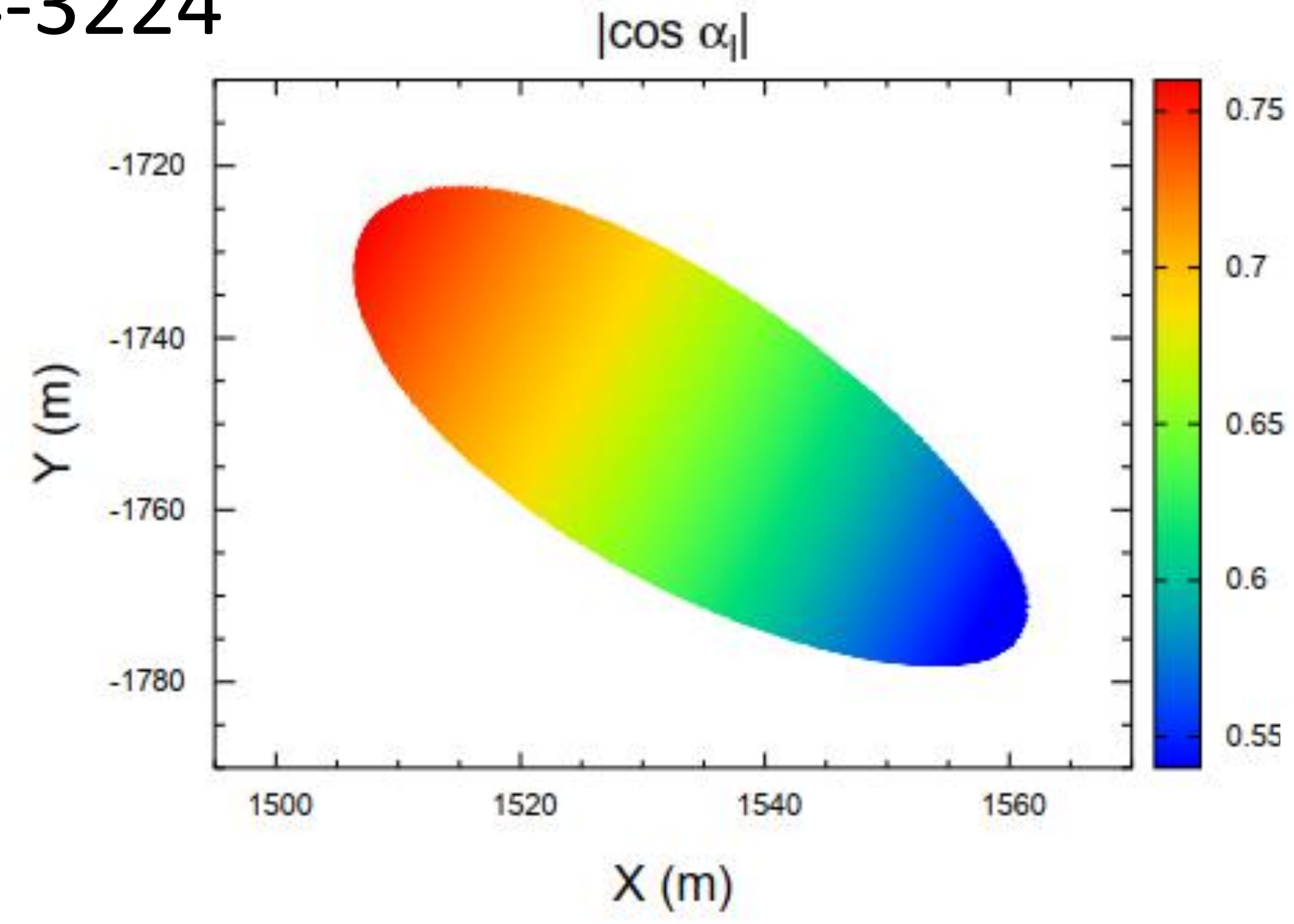
	a_{cap} (m)	b_{cap} (m)	θ_{cap} (°)	θ^c_{cap} (°)	ϕ^c_{cap} (°)	$b = B_s/B_d$	$\lvert\cos\alpha_l\rvert$	η	$h_\perp$ (m)	T_i (10^6 K)	ΔV_{PSG} (10^{10} V)
J1034−3224	36.2	15.1	-45.5	166.5	-48.8	~ 67	~ 0.65	0.034	4.3	1.17	1.56
J1720−2933	75.2	30.1	-36.8	37.1	20.9	~ 32	~ 0.25	0.26	8.8	3.93	22.4

Polar caps:

J1034-3224

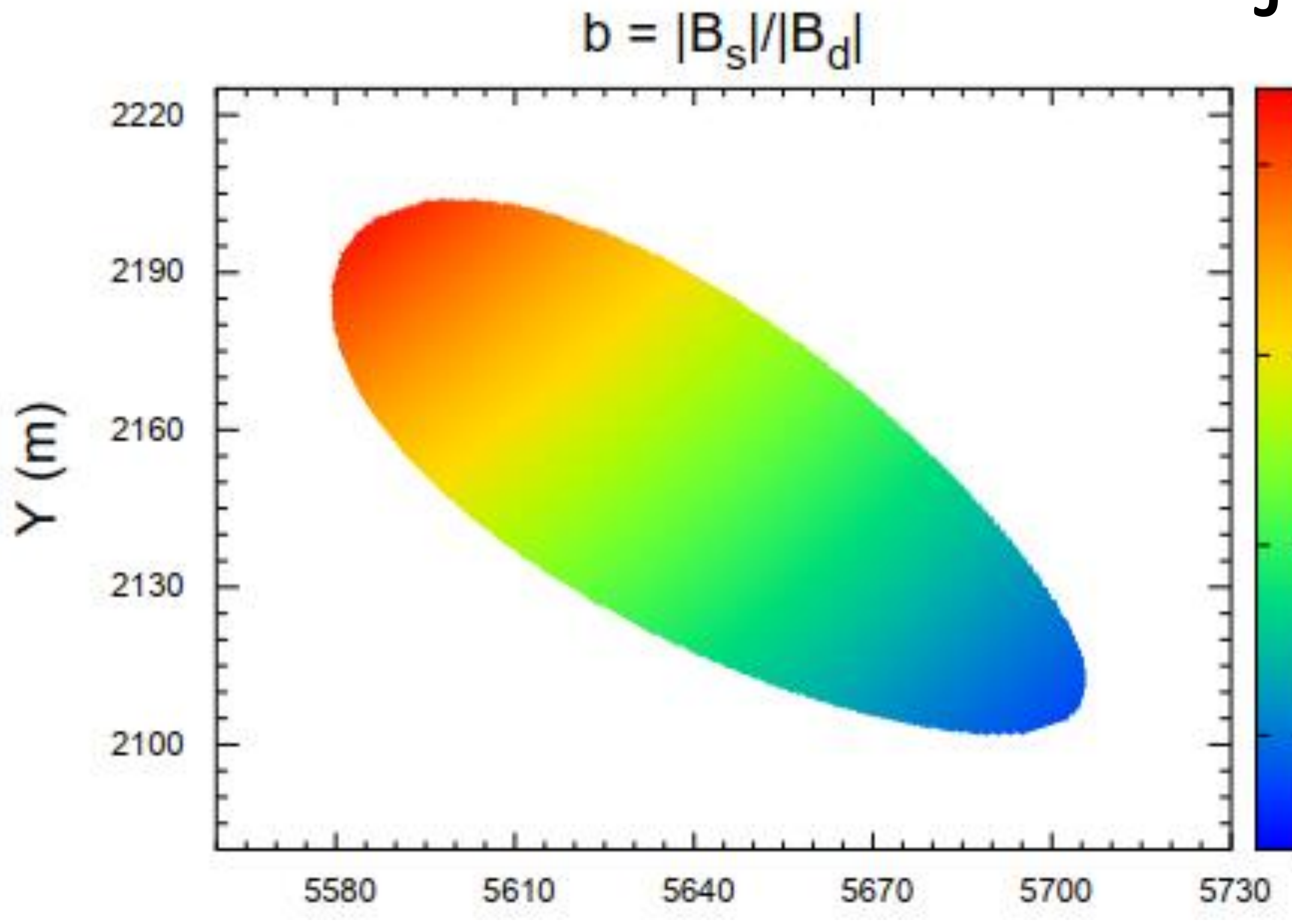


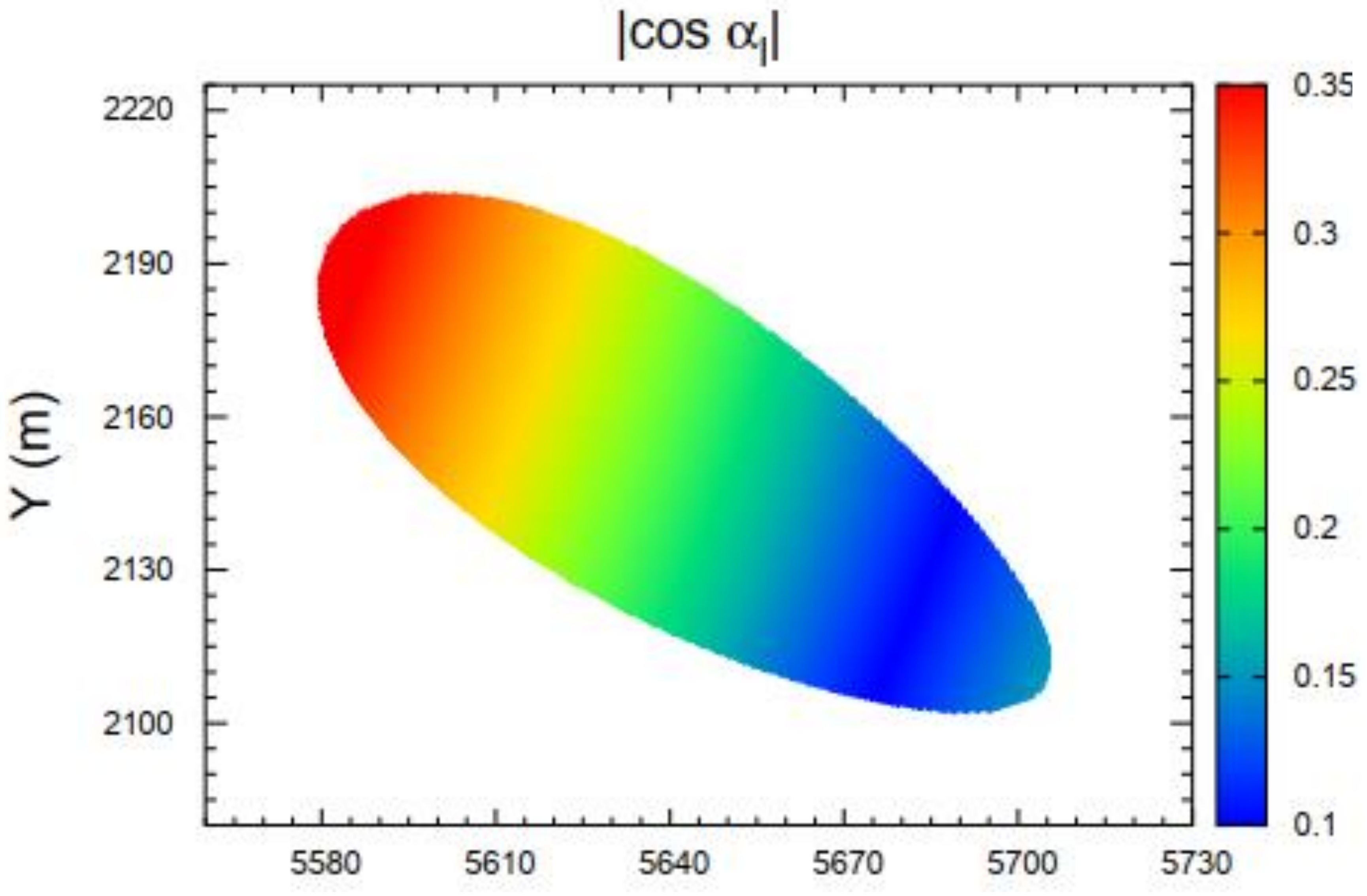
(a)

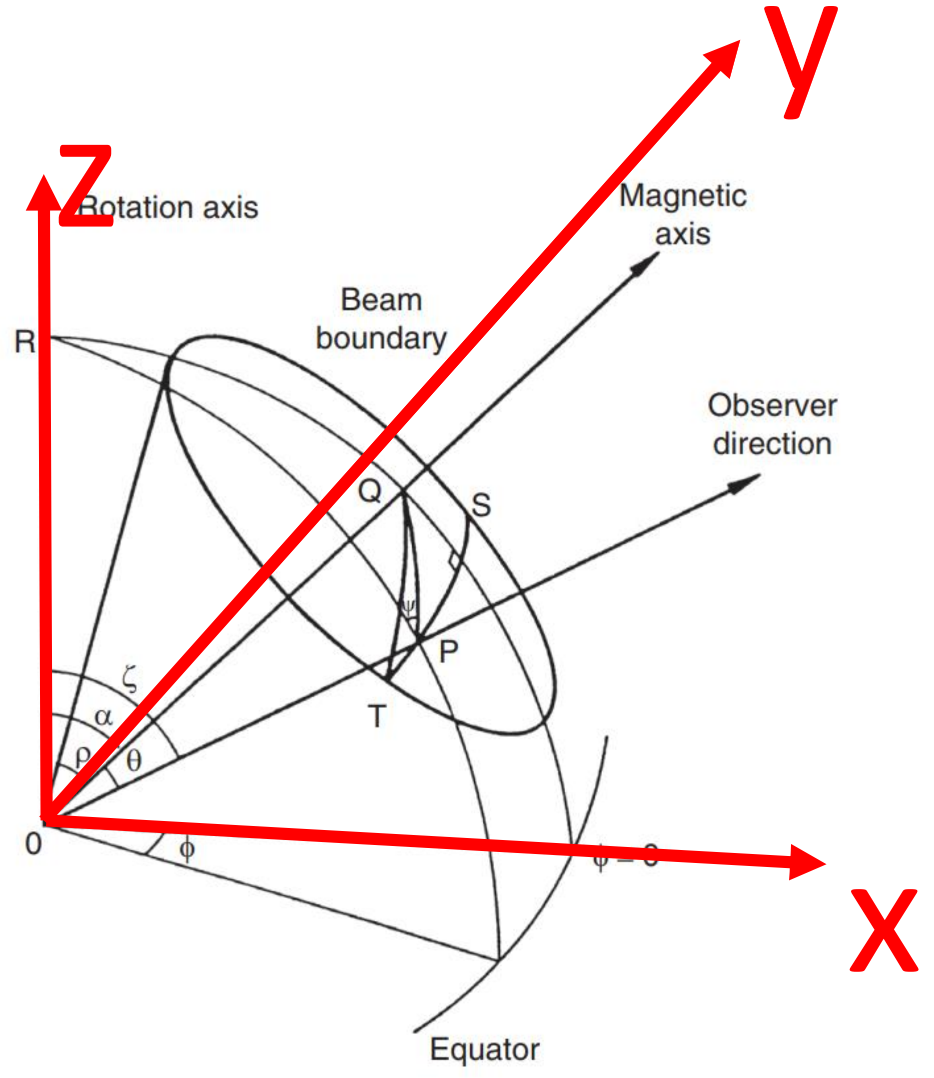


(b)

J1720-2933

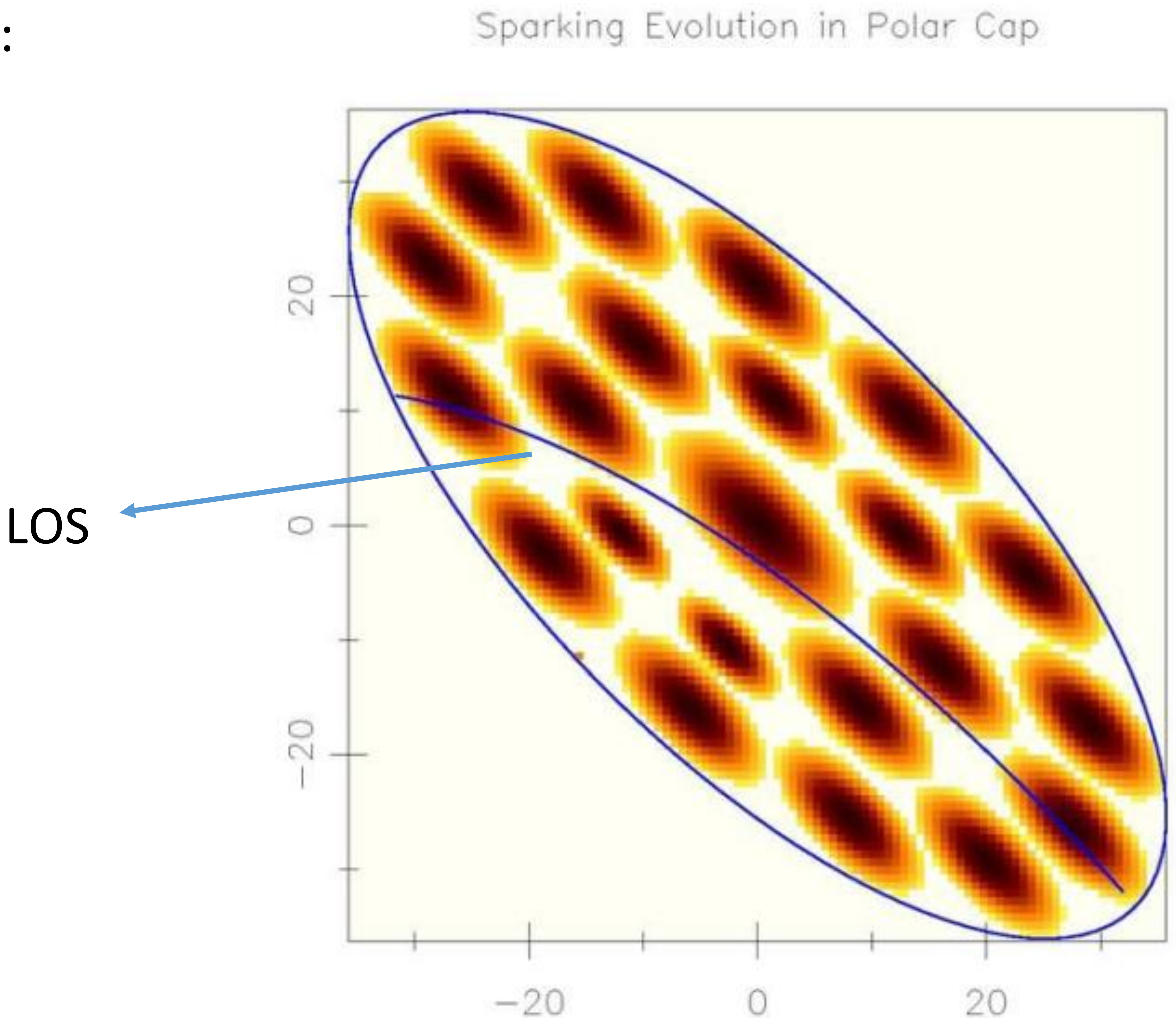






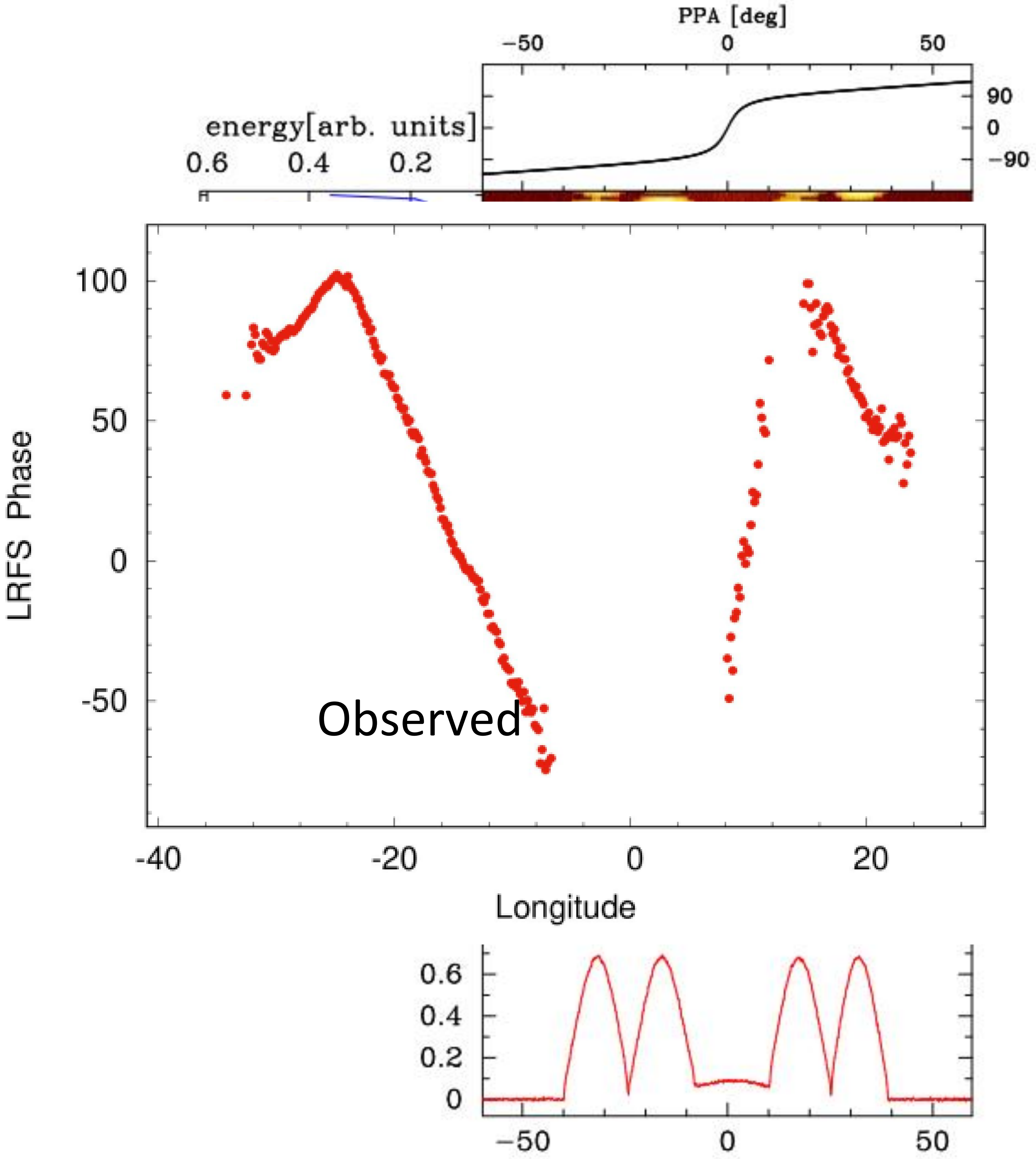
Simulation results:

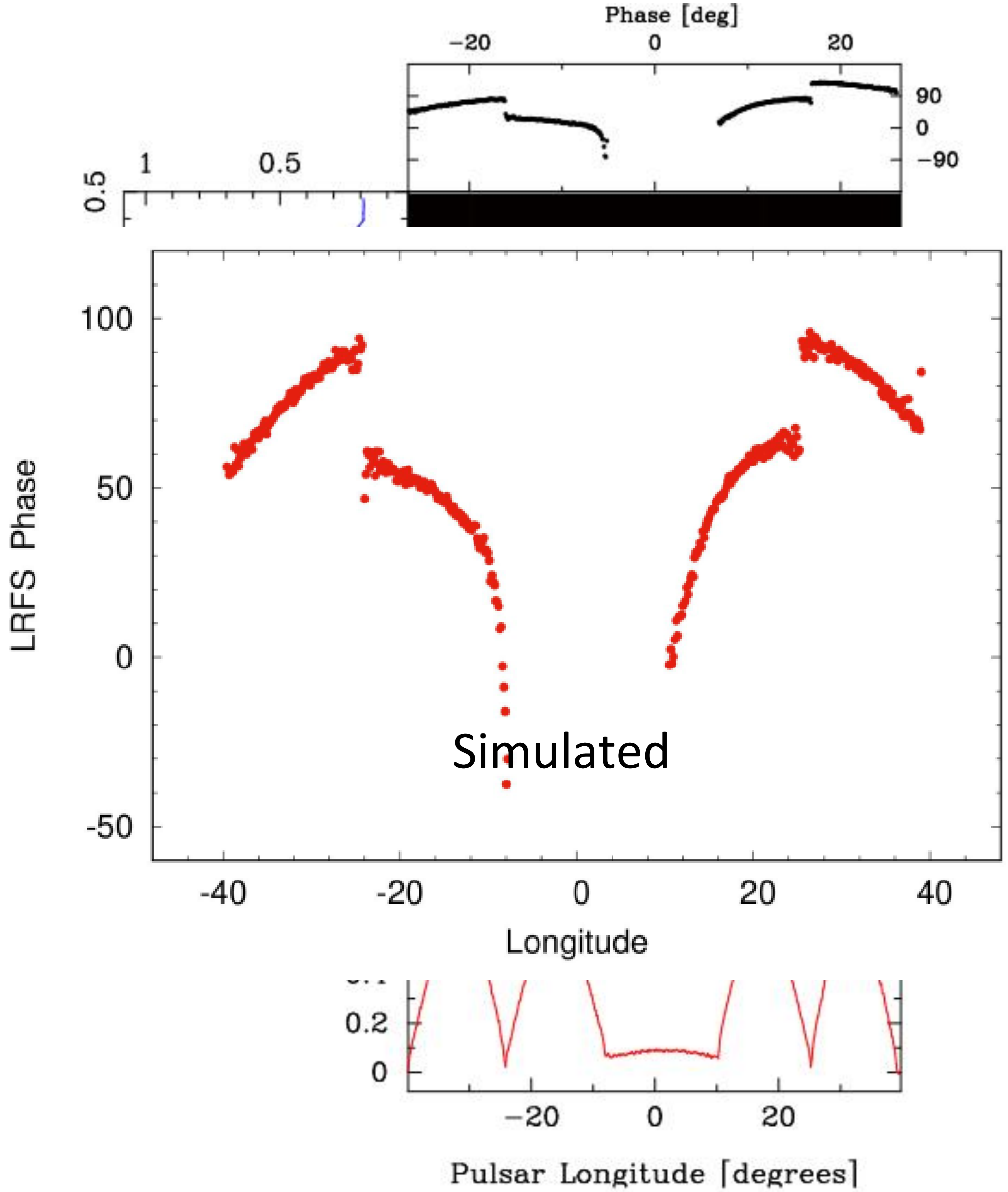
J1034-3224:



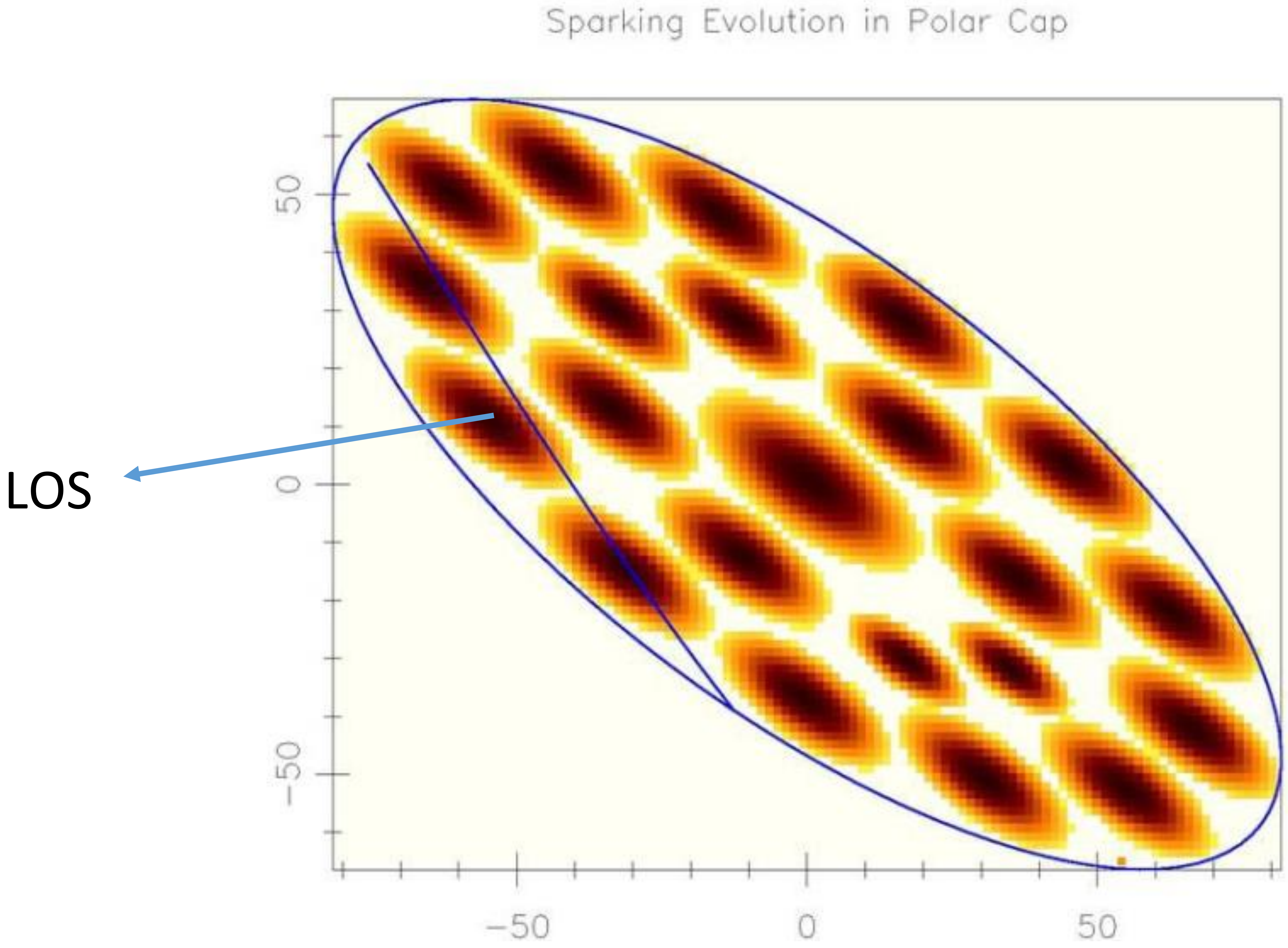
Simulation results:

J1034-3224:



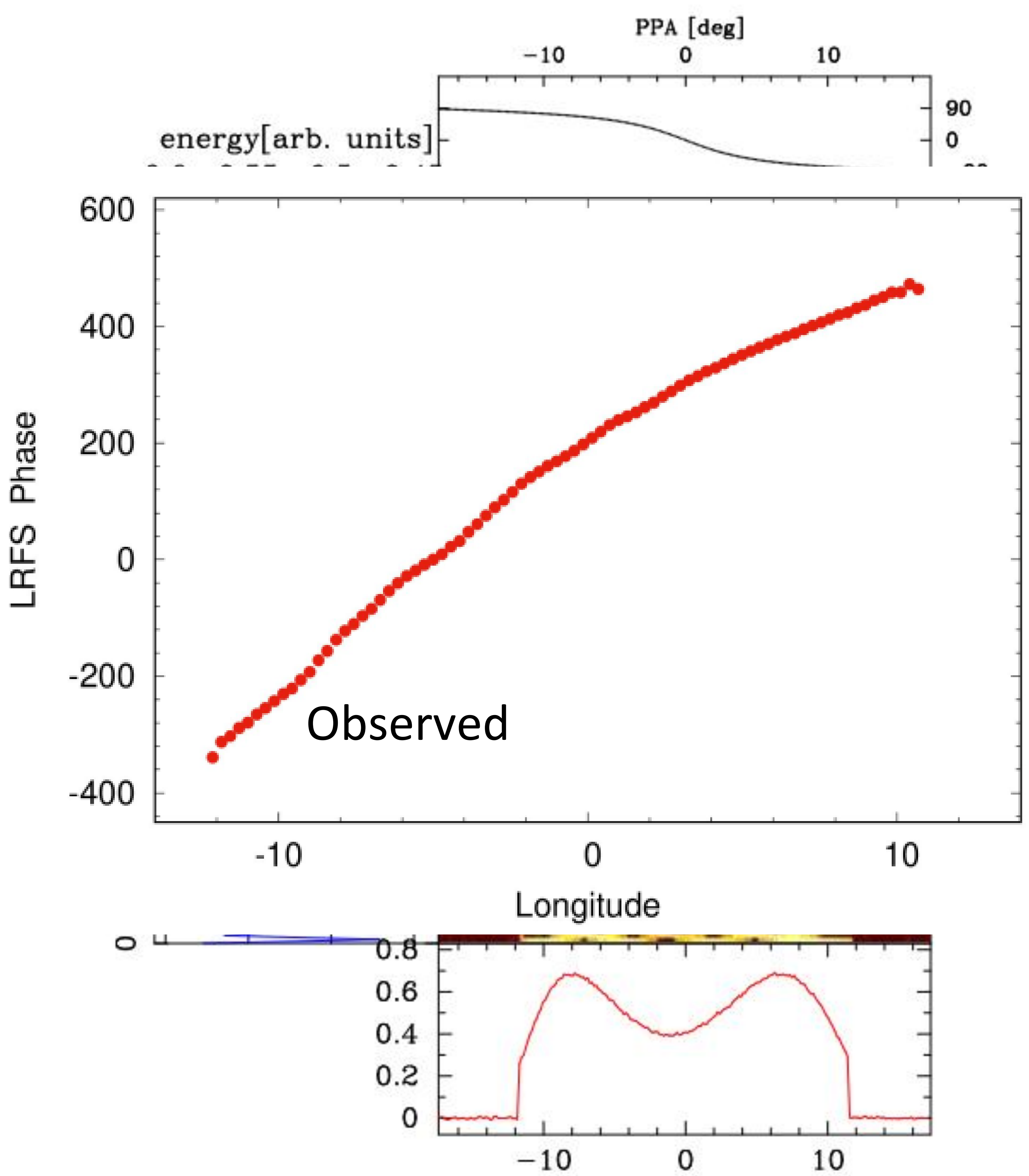


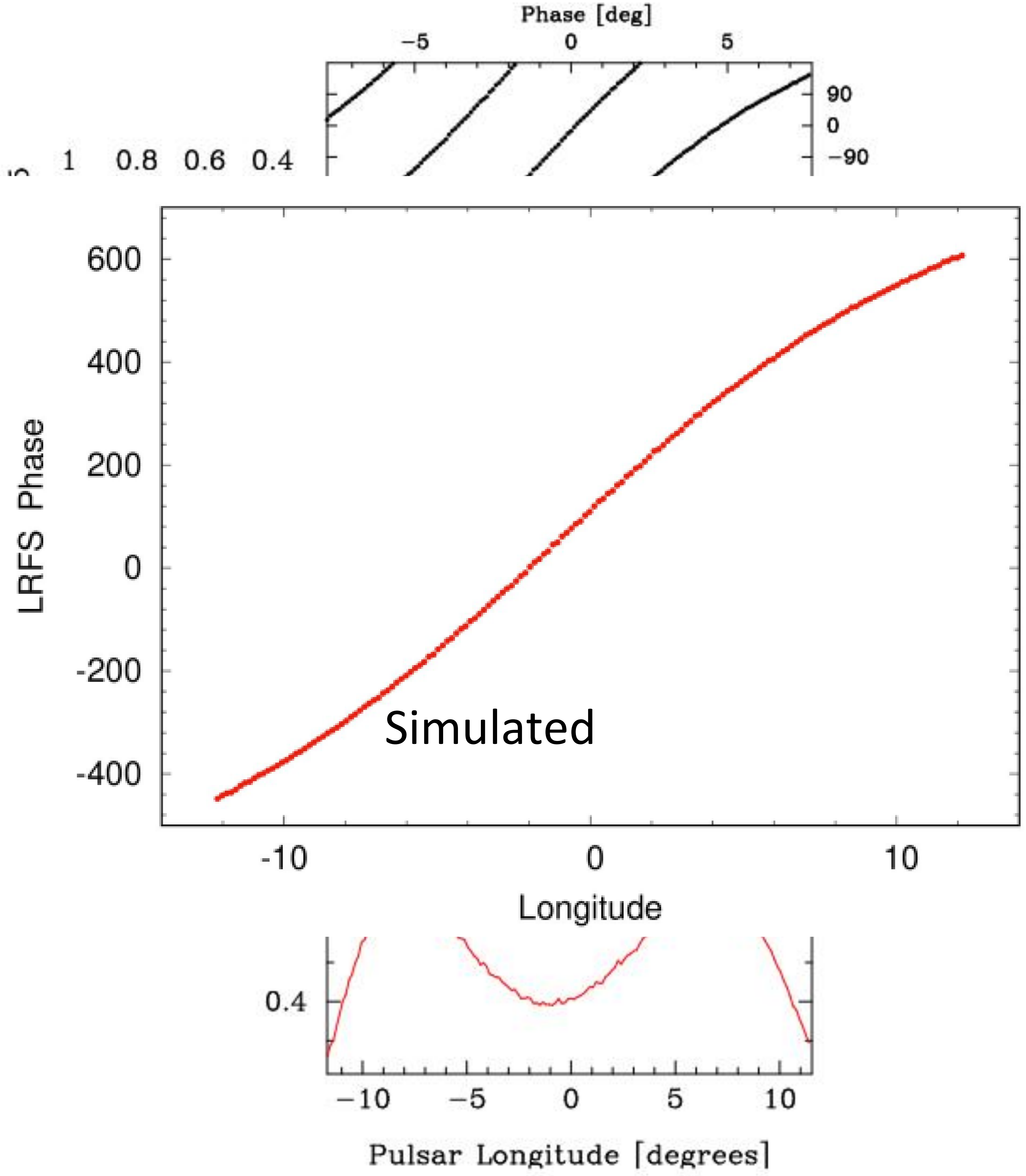
Simulation results:
J1720-2933:



Simulation results:

J1720-2933:





Thank you for your attention