Emission Beam of Radio Pulsars

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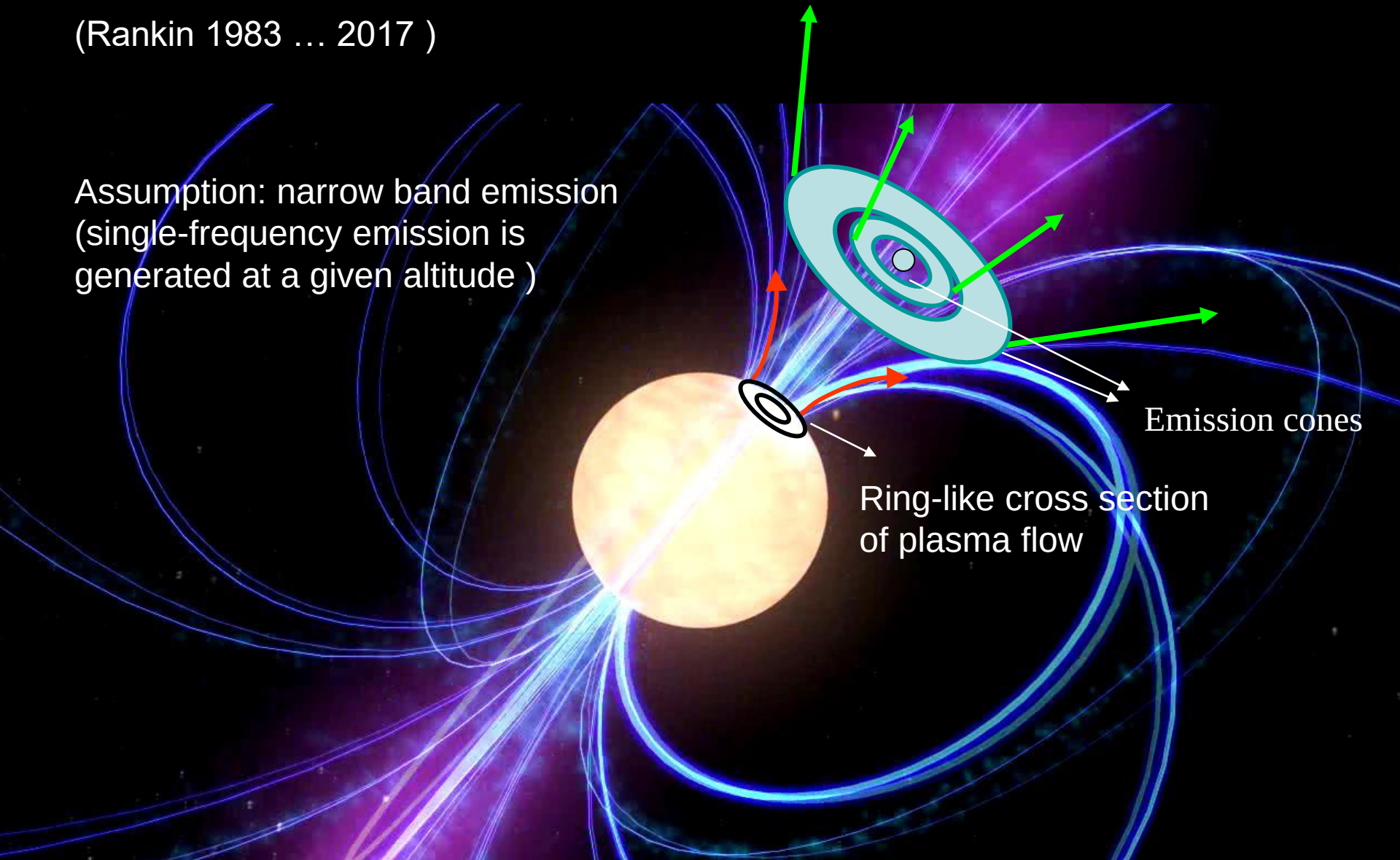
Outline

1. Radio beam models
2. Observational tests
3. Other work

Radio beam model – conal beam

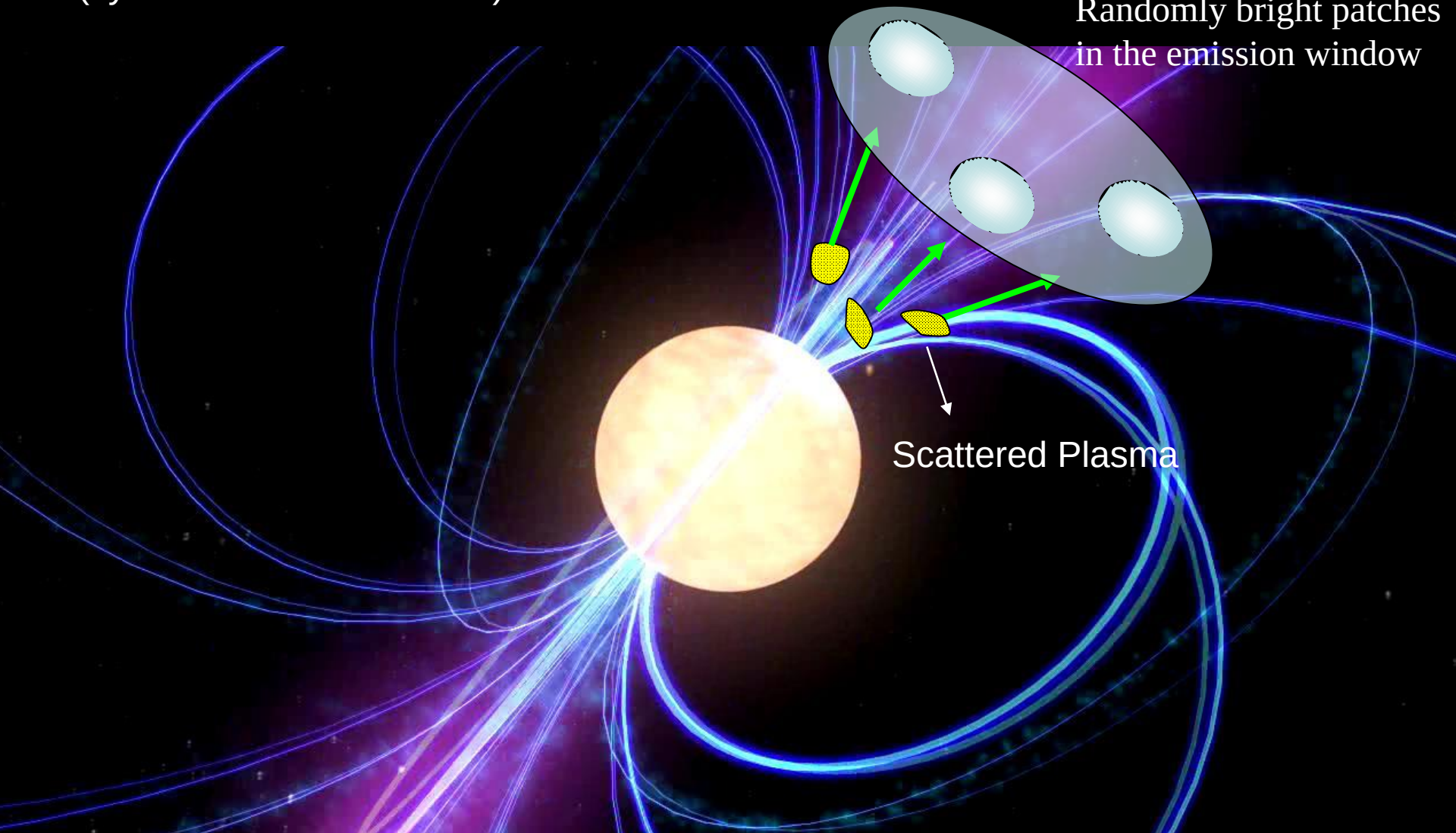
(Rankin 1983 … 2017)

Assumption: narrow band emission
(single-frequency emission is
generated at a given altitude)



Radio beam model – patchy beam

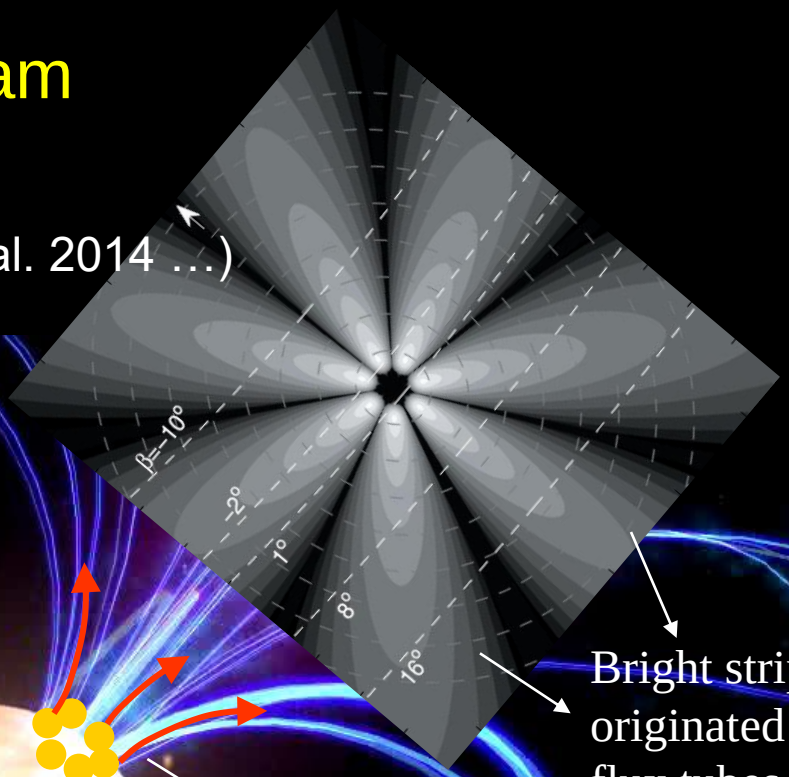
(Lyne & Manchester 1988)



Radio beam model – fan beam

(Michel 1987, Dyks et al. 2010, Wang et al. 2014 …)

Assumption: broadband emission
(multifrequency emission is
generated at a given altitude)

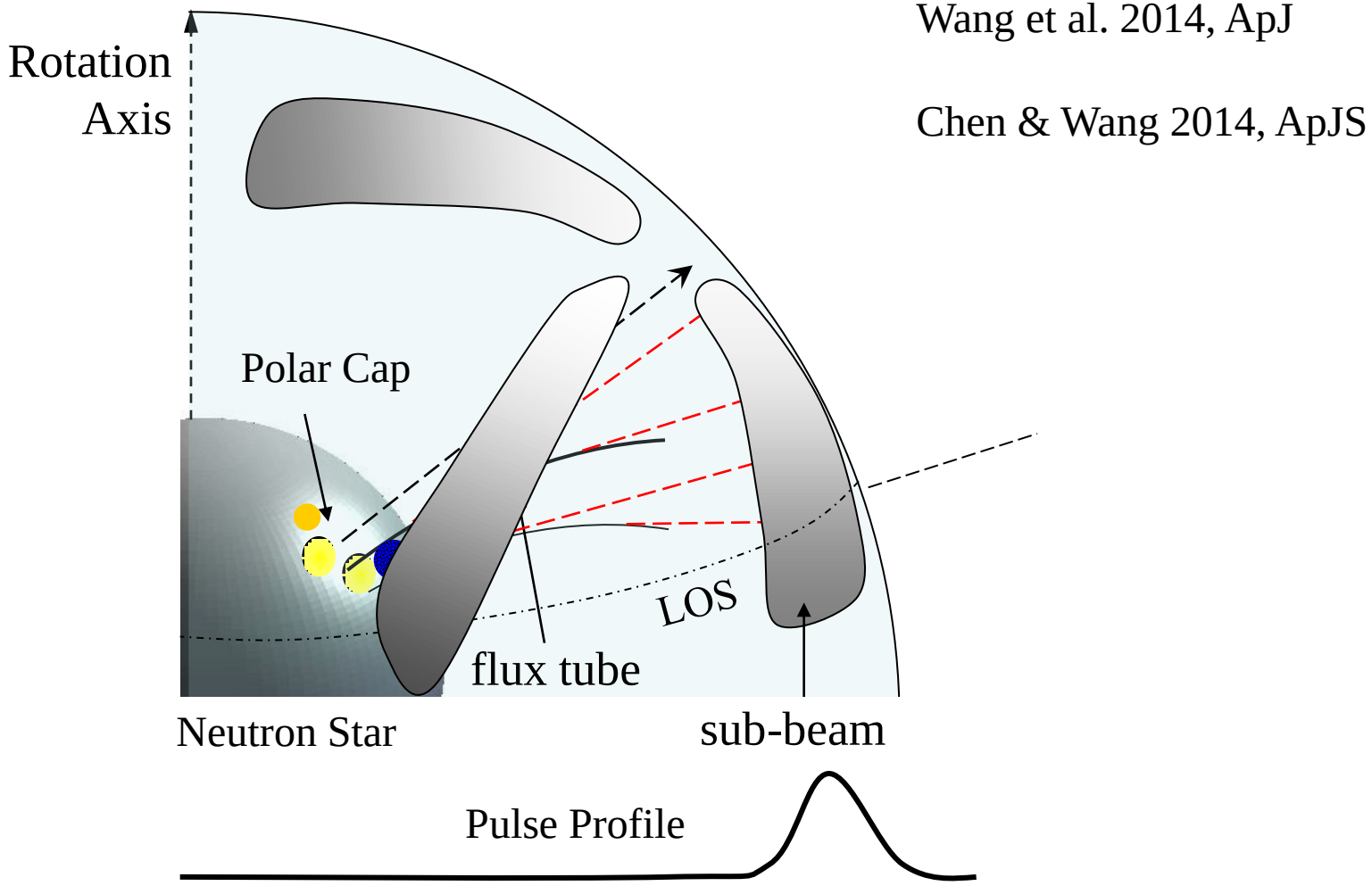


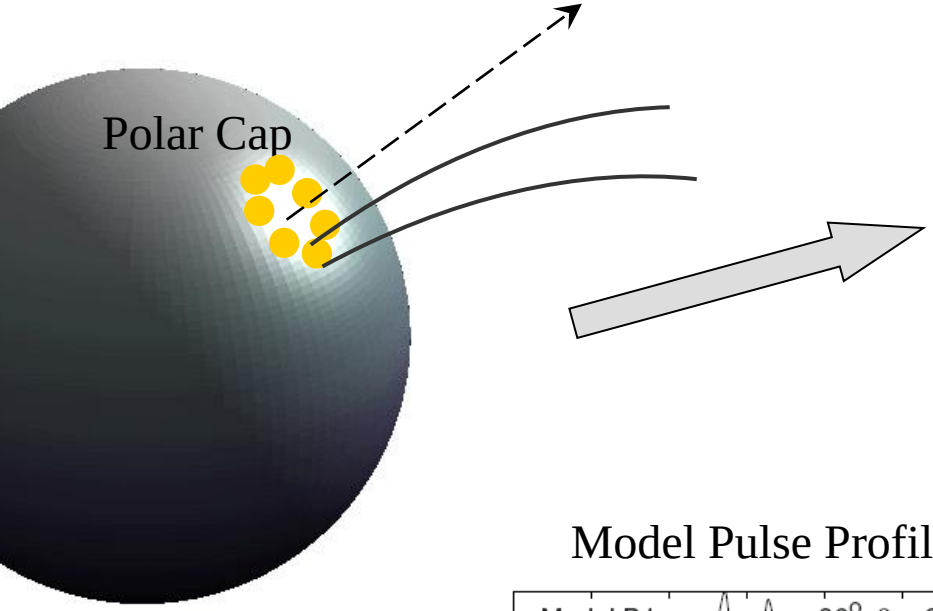
Bright stripes
originated from
flux tubes

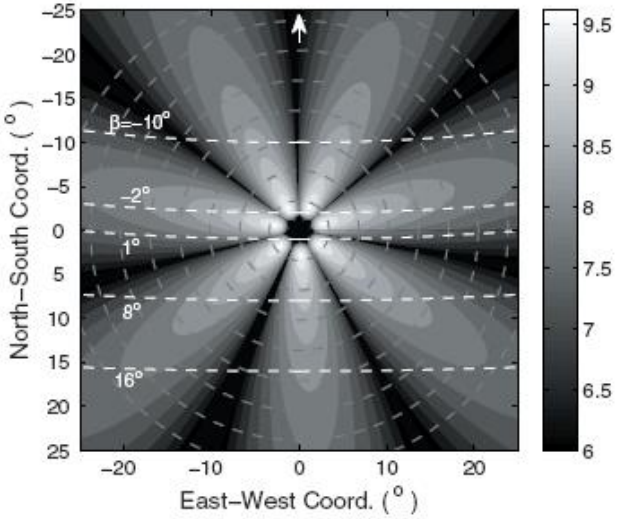
Plasma flow
along flux tubes

Wang et al. 2014, ApJ

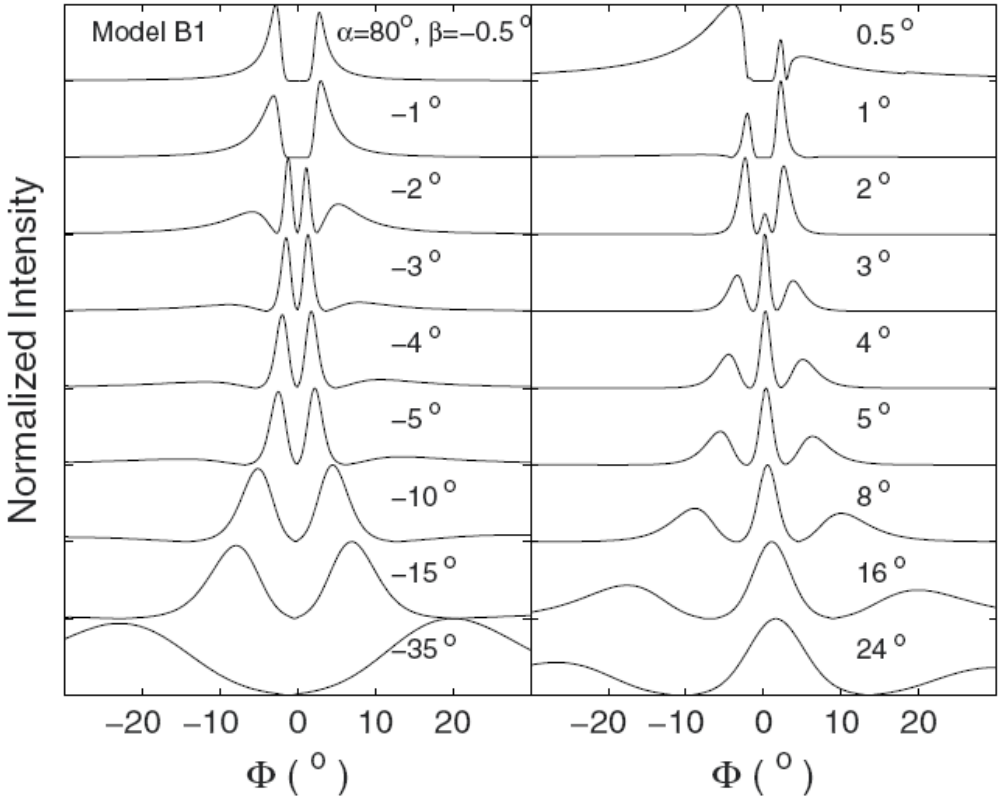
Chen & Wang 2014, ApJS





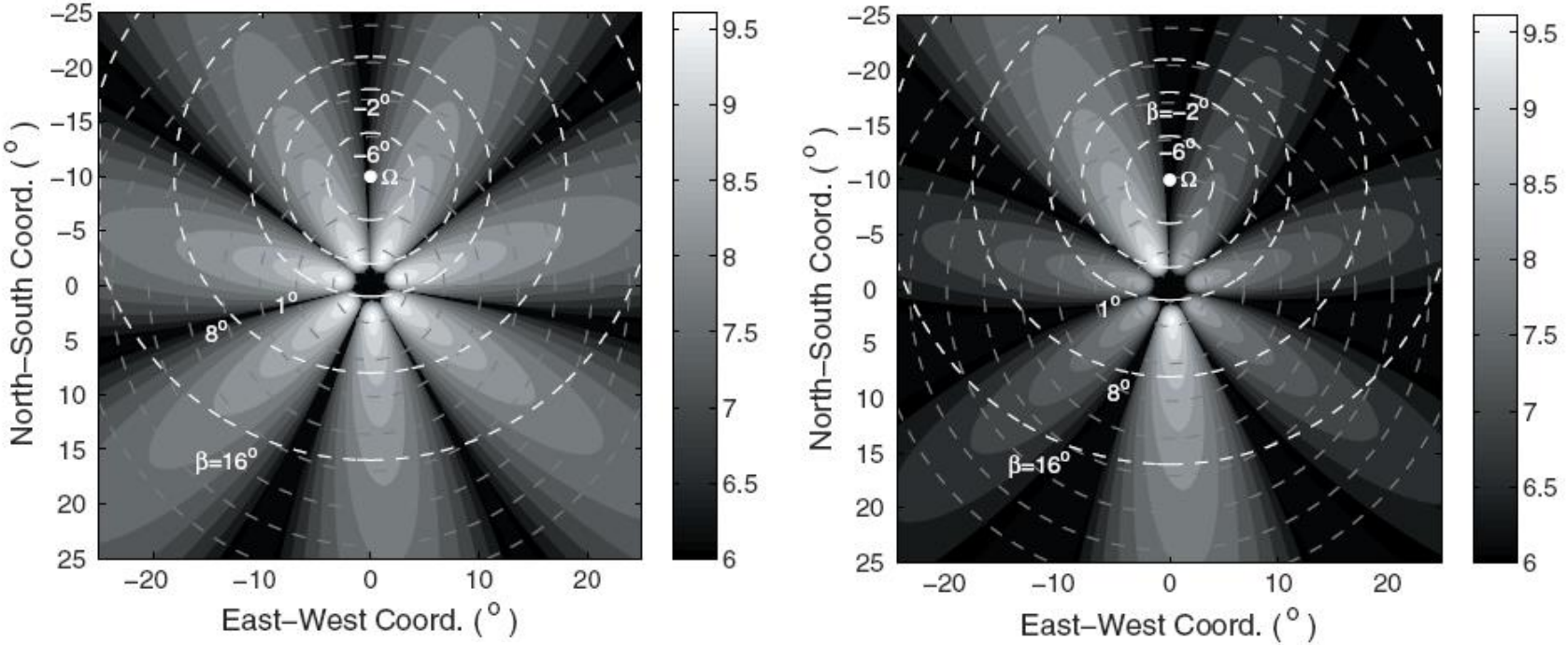


Model Pulse Profile



The beam structure depends on particle flow & emission process

Density distribution of particles above the polar cap



2-D beam structure for the B2 particle distribution

2. Observational tests

Test 1 2-D beam structure of precessional pulsars

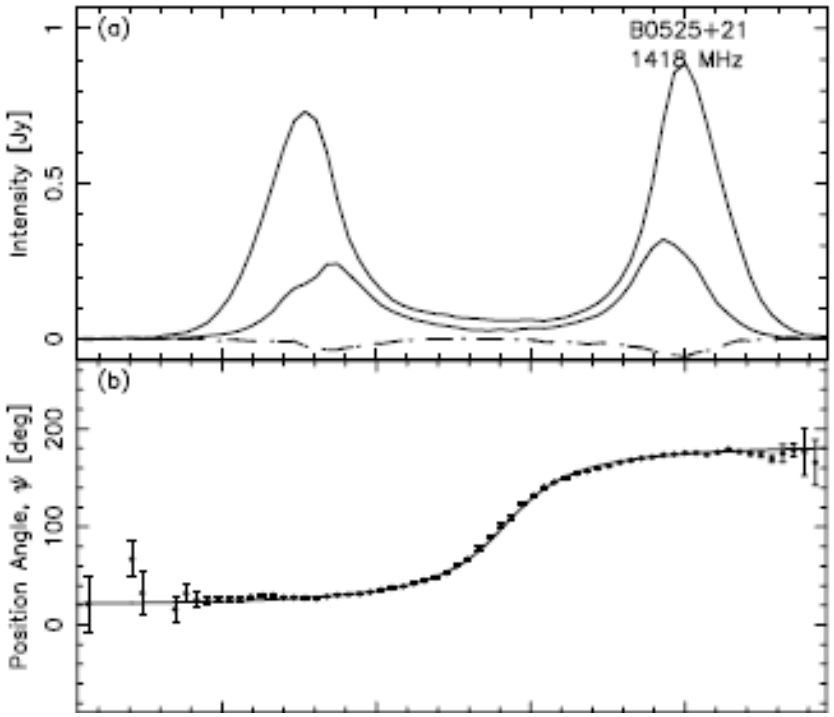
Precessional Binary Pulsars (Kramer et al. 2012 review)

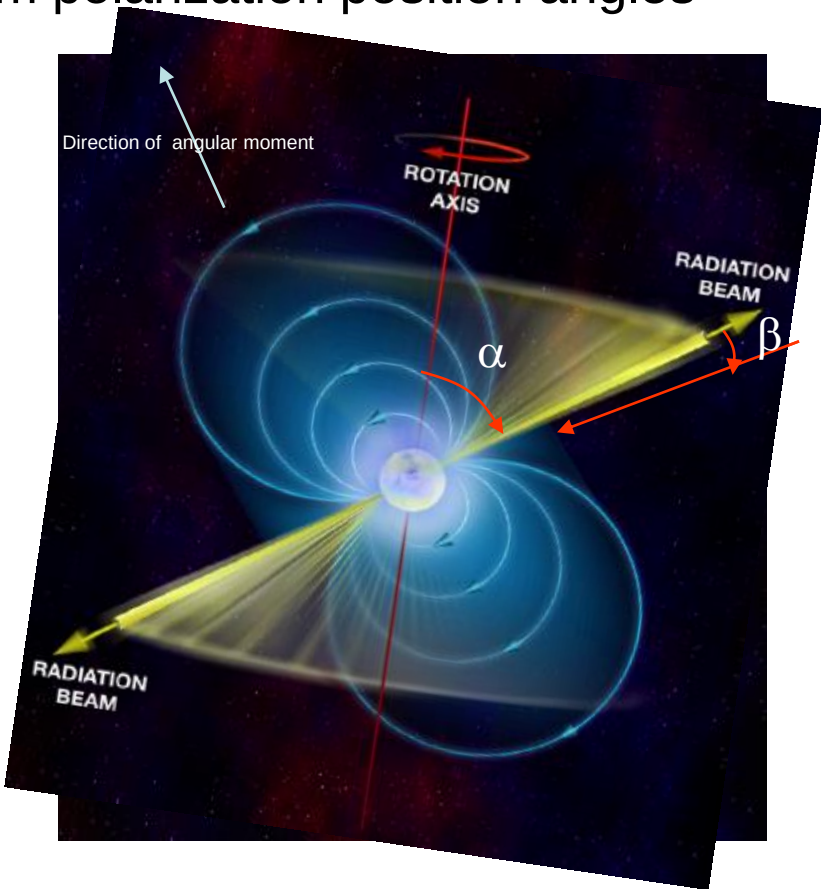
PSR	P(ms)	P_b (d)	x(lt-s)	e	Ω_p (deg yr^{-1})	S1400(mJy)
J0737−3039A/B*	22.7/2770	0.10	1.42/1.51	0.09	4.8/5.1	1.6/1.3
J1906+0746*	144.1	0.17	1.42	0.09	2.2	0.55->0.115
B2127+11C*	30.5	0.34	2.52	0.68	1.9	
B1913+16*	59.0	0.33	2.34	0.62	1.2	0.9
J1756−2251	28.5	0.32	2.76	0.18	0.8	0.6
B1534+12*	37.9	0.42	3.73	0.27	0.5	0.6
J1829+2456	41.0	1.18	7.24	0.14	0.08	
J1518+4904	40.9	8.64	20.0	0.25	–	4
J1753−2240	95.1	13.63	18.1	0.30	–	0.15
J1811−1736	104.2	18.8	34.8	0.83	–	1.3
J1141−6545*	394.0	0.20	1.89	0.17	1.4	3.3

2305+4707

All the monitoring are between 400MHz and 1400MHz.
High frequency beam structure is unknown.

constraints on viewing geometry from polarization position angles

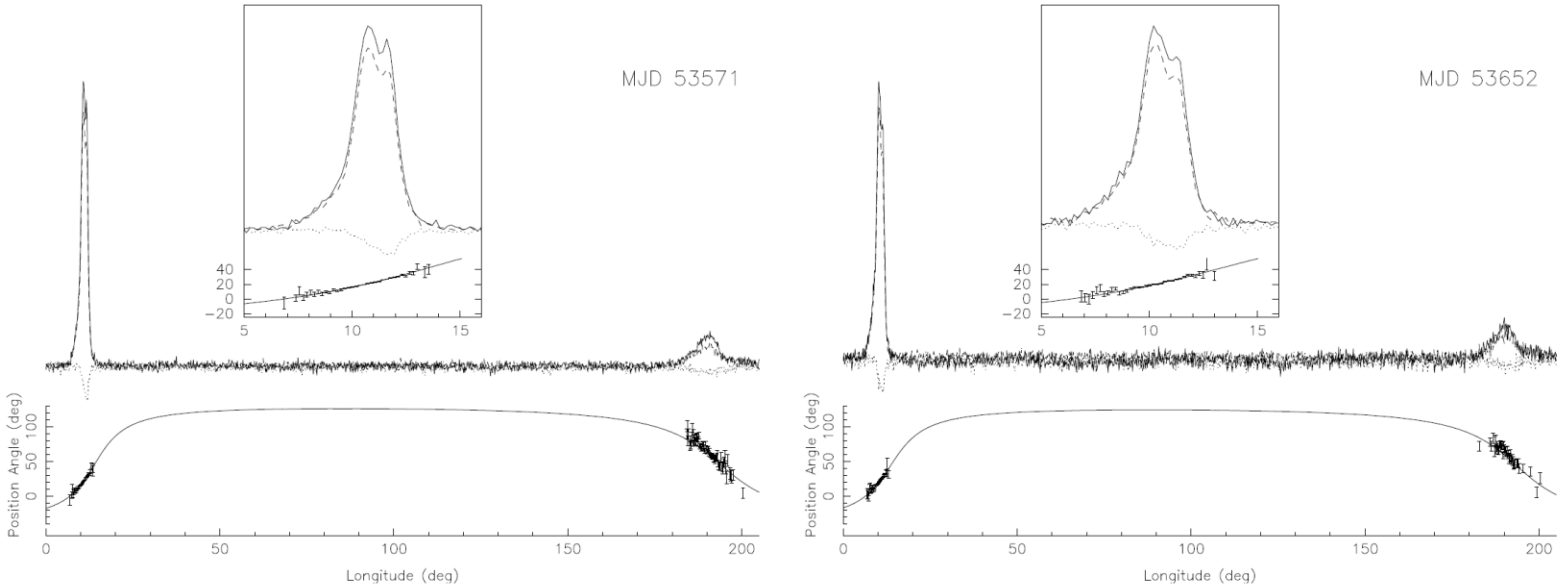




Rotating Vector Model (Radhakrishnan & Cooke 1969)

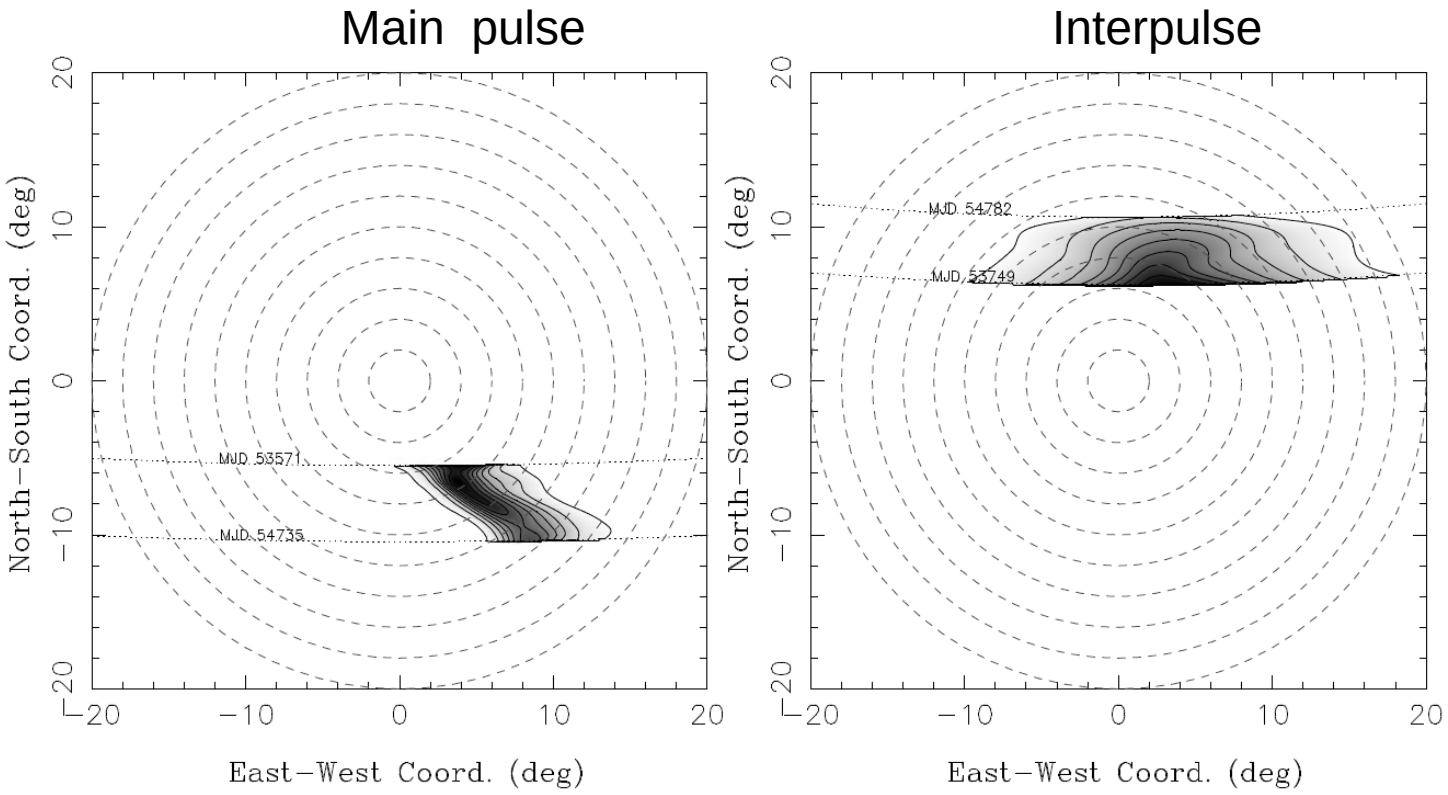
$$\tan(\psi' - \psi'_0) = \frac{\sin\alpha \sin(\phi - \phi_0)}{\sin\zeta \cos\alpha - \cos\zeta \sin\alpha \cos(\phi - \phi_0)}$$

J1906+0746 Desvignes et al. 2012, 2013



MJD	β (deg)	ψ_0 (deg)	RM (rad m^{-2})
53571	6.83 ± 0.32	45.6 ± 1.2	156 ± 2
53652	7.37 ± 0.53	43.9 ± 1.5	146 ± 2
53750	7.75 ± 0.92	41.2 ± 3.1	155 ± 4
53843	7.90 ± 0.80	39.7 ± 4.2	140 ± 5
53925	8.21 ± 1.25	44.7 ± 3.2	152 ± 6
54023	8.94 ± 1.52	45.2 ± 3.9	145 ± 4
54109	9.44 ± 0.92	42.5 ± 2.3	137 ± 3
54190	9.34 ± 0.91	43.2 ± 2.9	147 ± 3
54282	9.79 ± 1.04	43.4 ± 3.7	126 ± 3

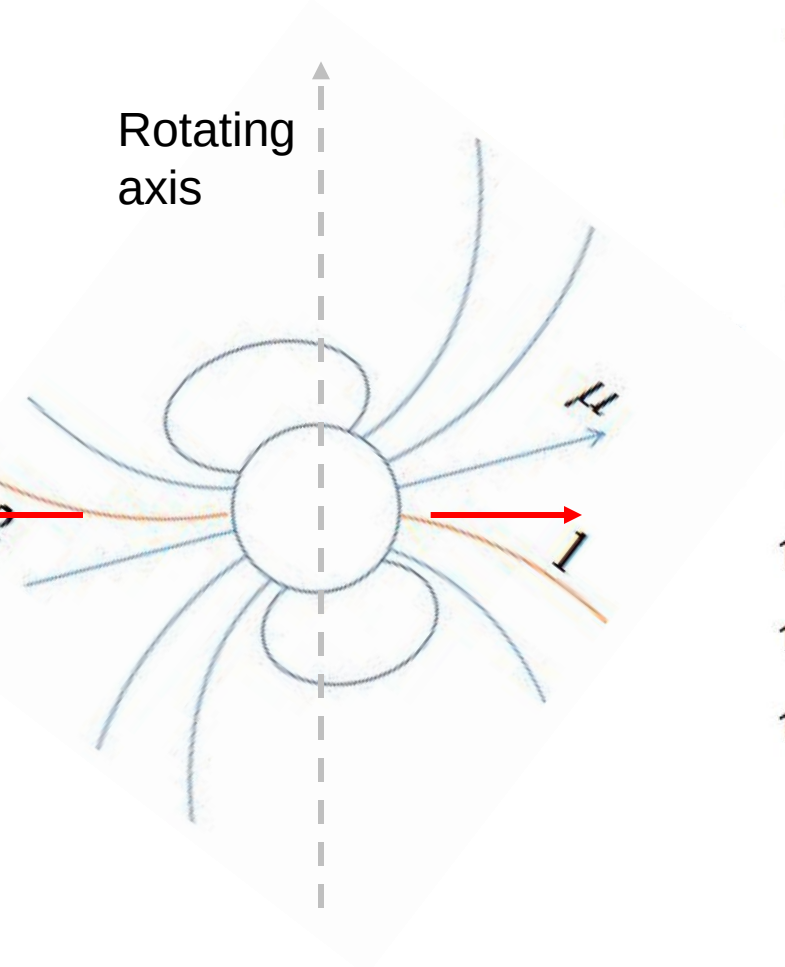
Reconstructed beam of J1906+0746

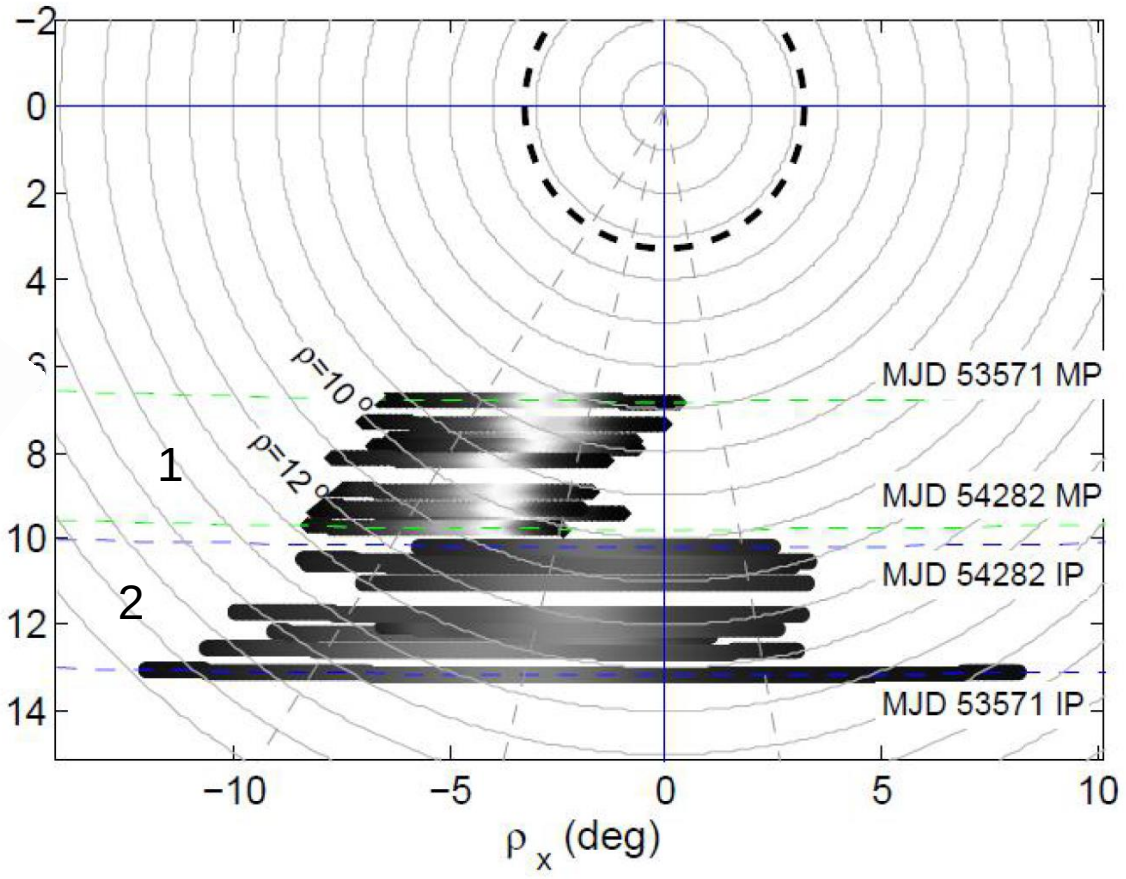


Updated results: emission beams from two poles possibly have different structure

Main pulse

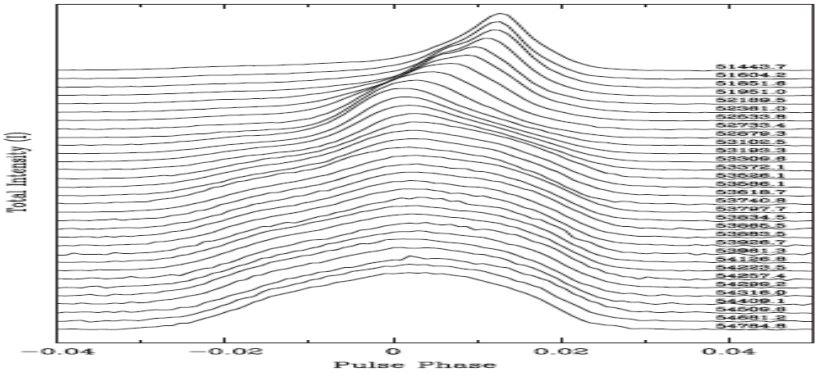
Interpulse

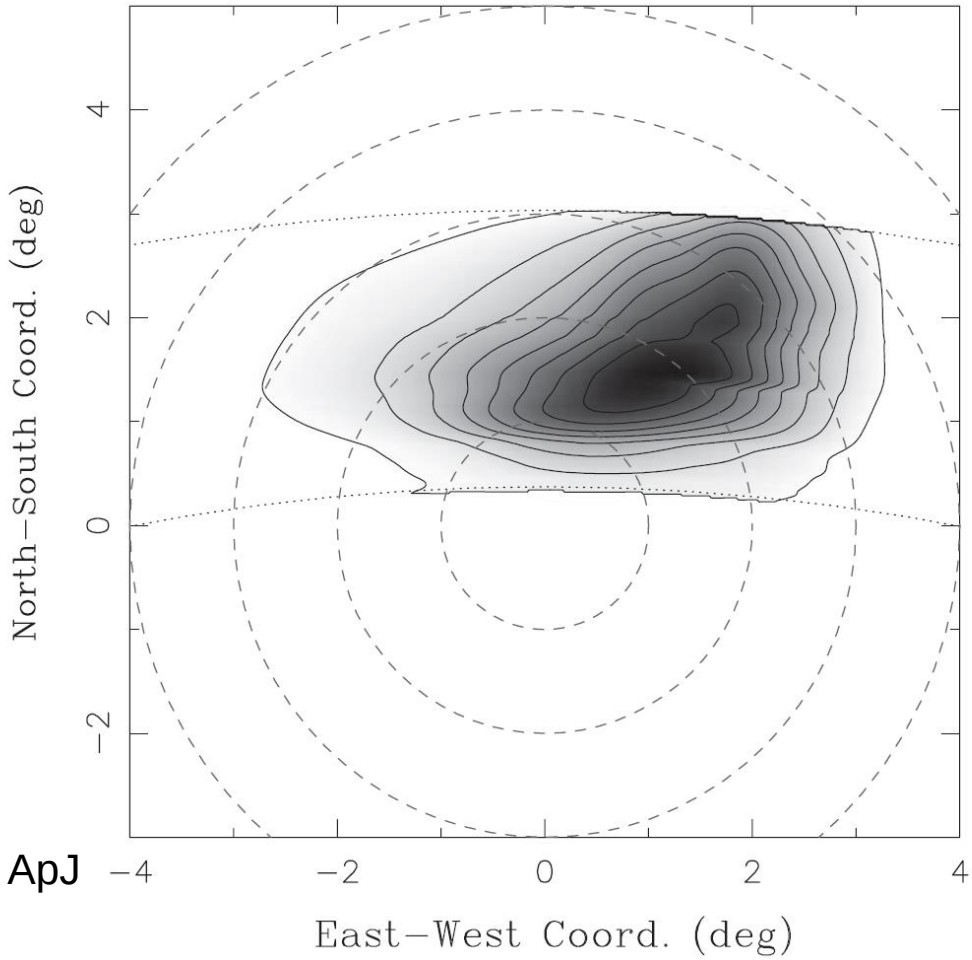




Huang et al. in prep.

J1141-6545

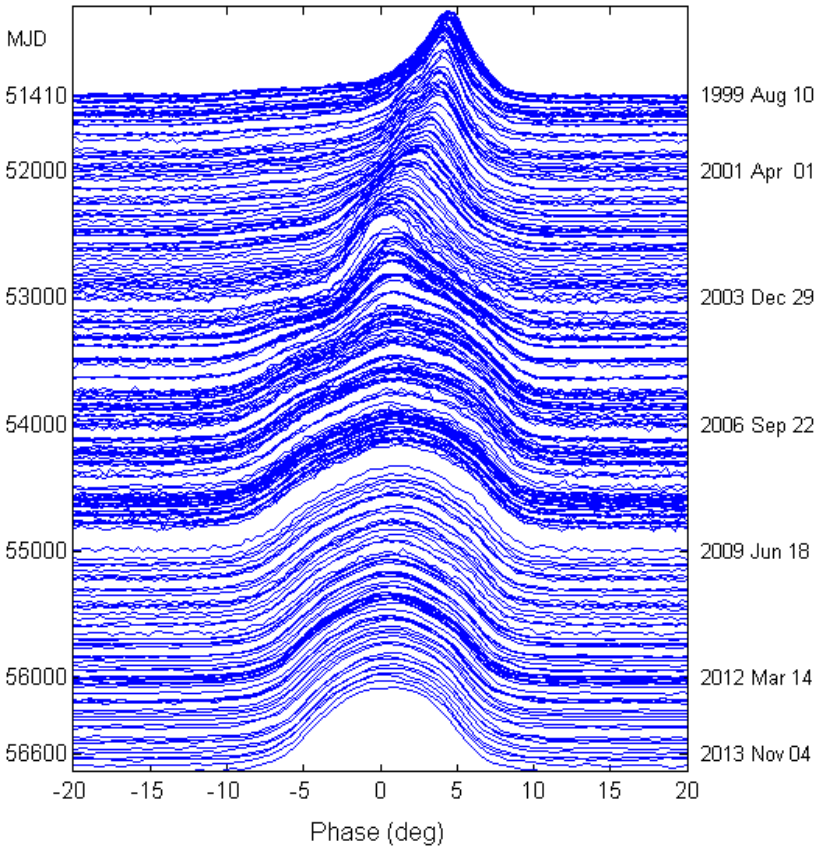




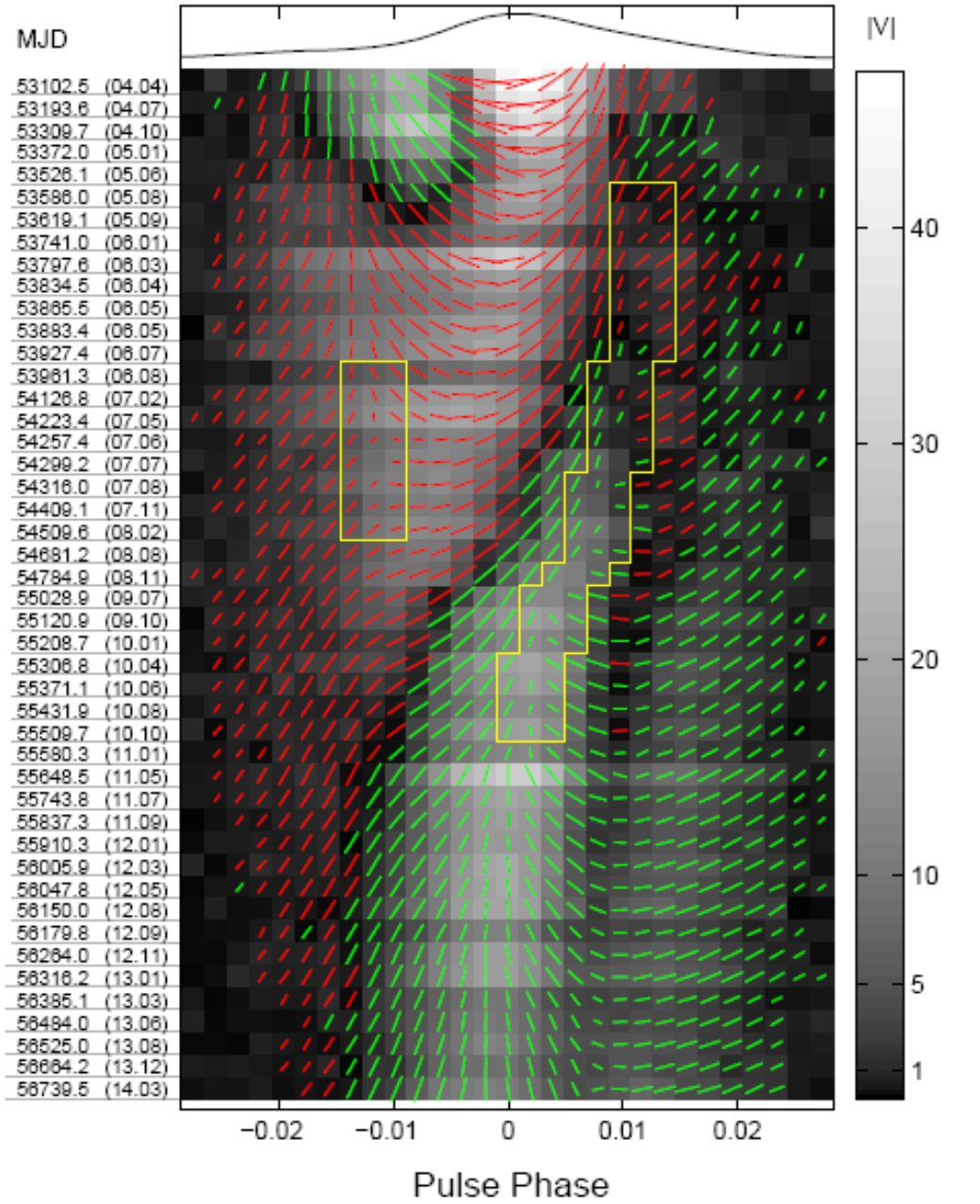
Manchester et al. 2010 ApJ
Parkes

Updated results of J1141-6545 (1999-2014)

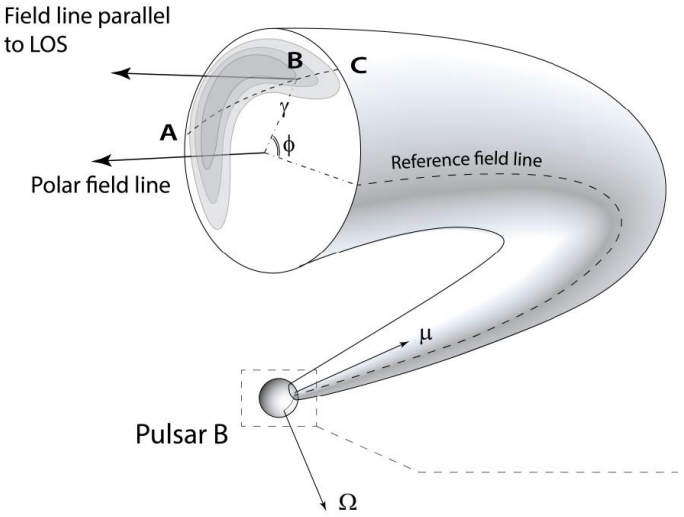
Profile evolution

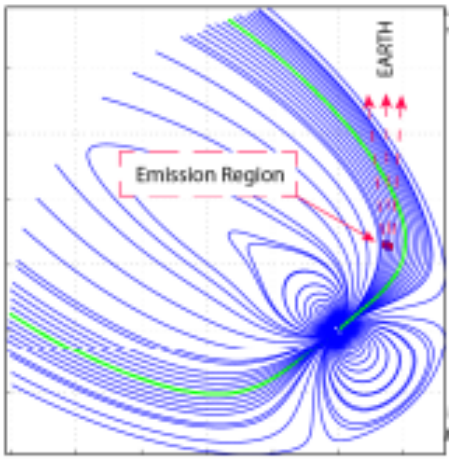


Evolution of polarization



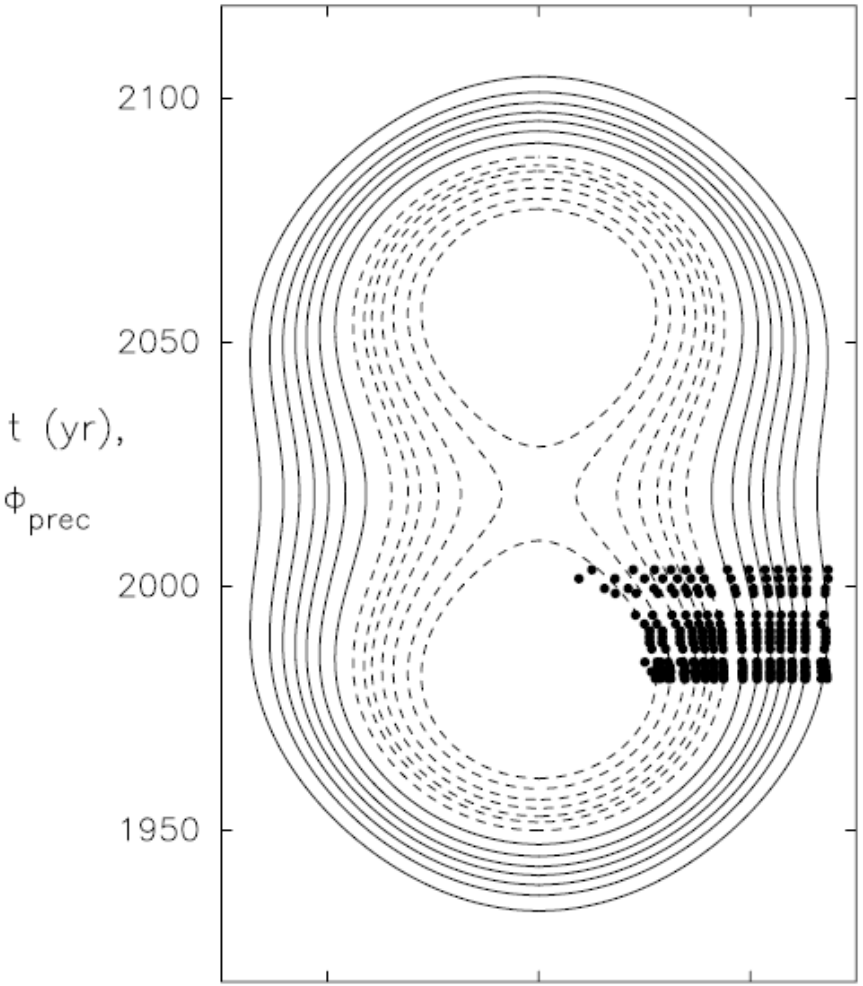
PSR J0737-3093B





Lomiashvili and Lyutikov 2014 MNRAS
GBT

PSR B1913+16

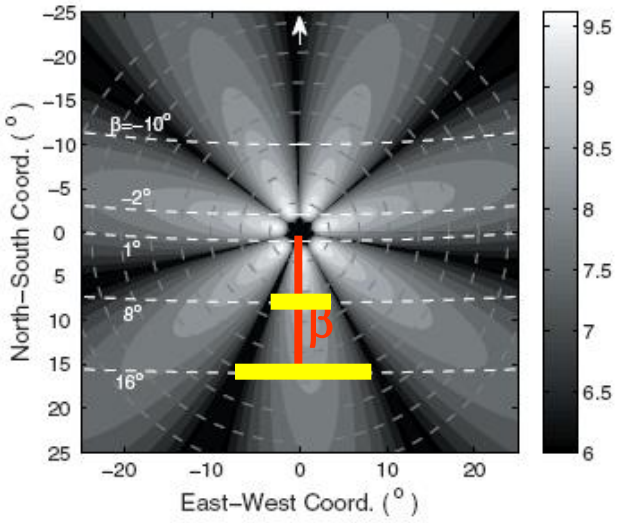


Clifton & Weisberg 2008 ApJ
Arecibo

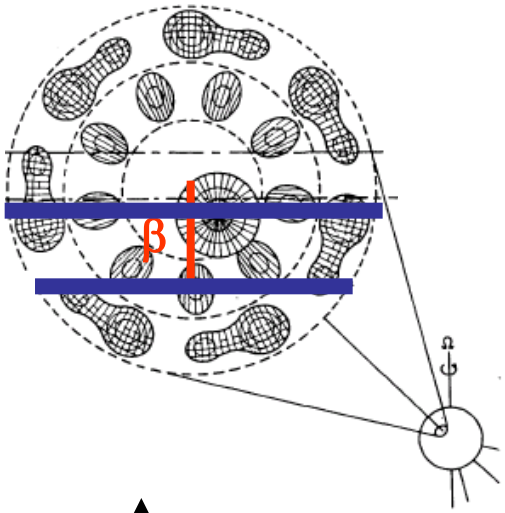
Test 2 Statistics. Pulse width - impact angle relationship

Model Prediction

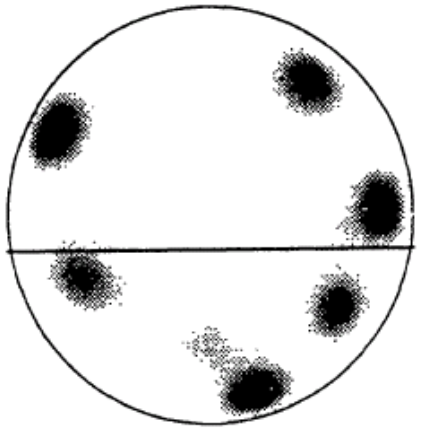
Fan beam

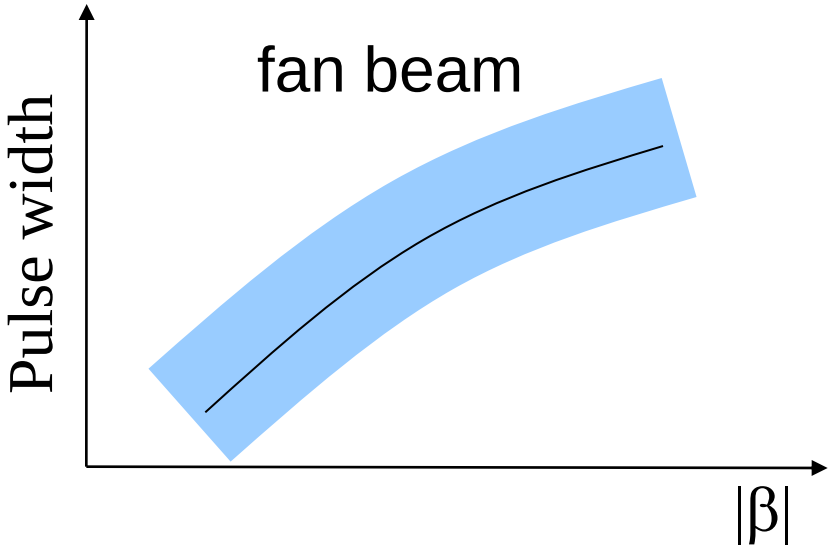


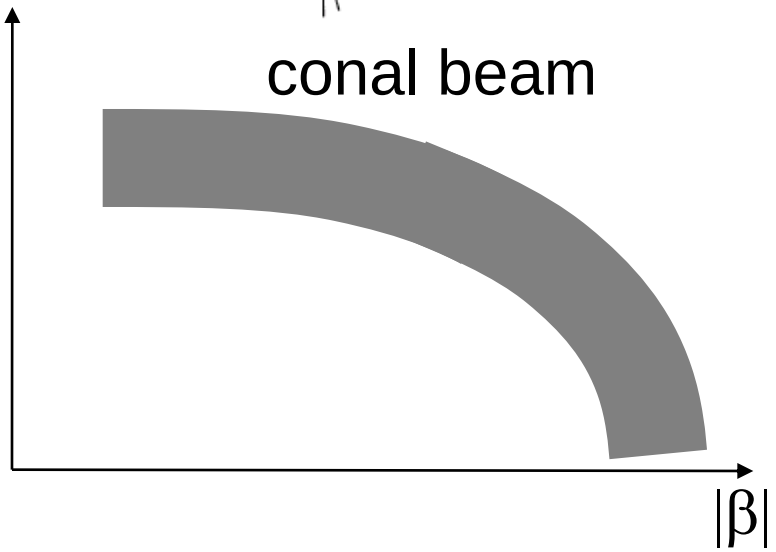
Conal beam



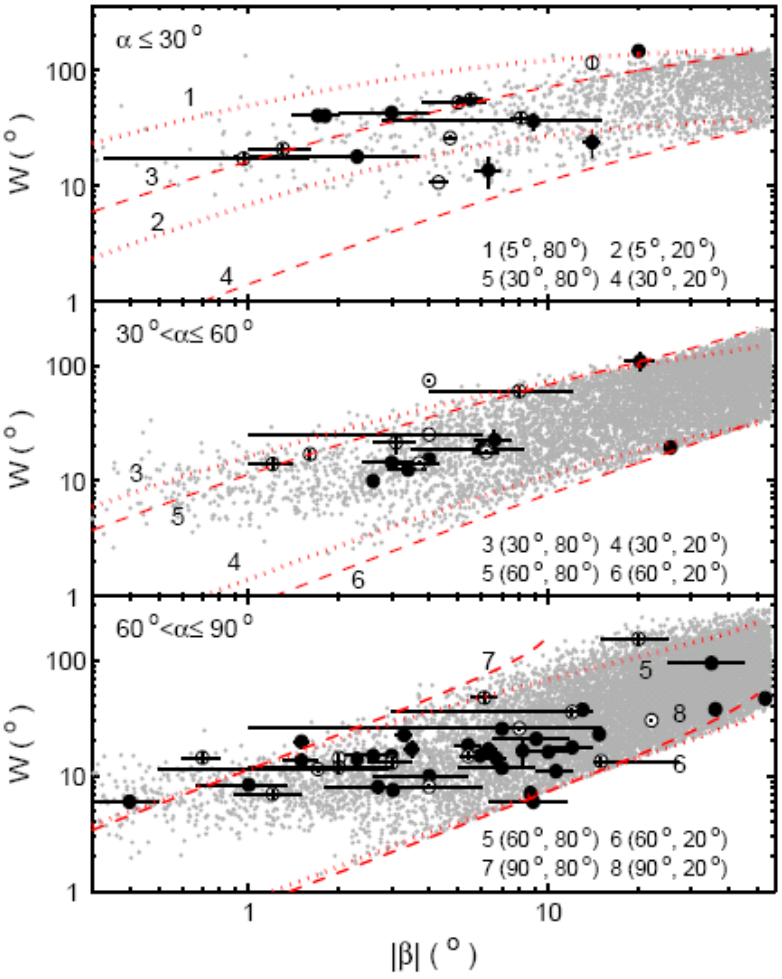
Patchy beam



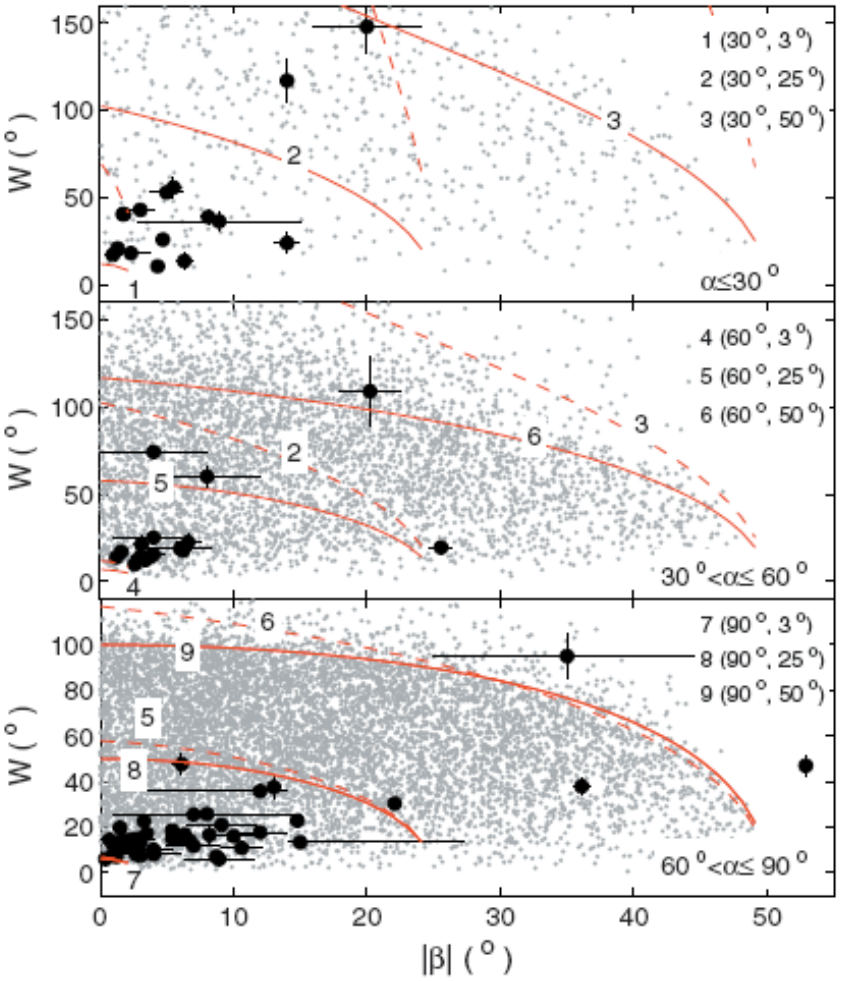




Fan beam



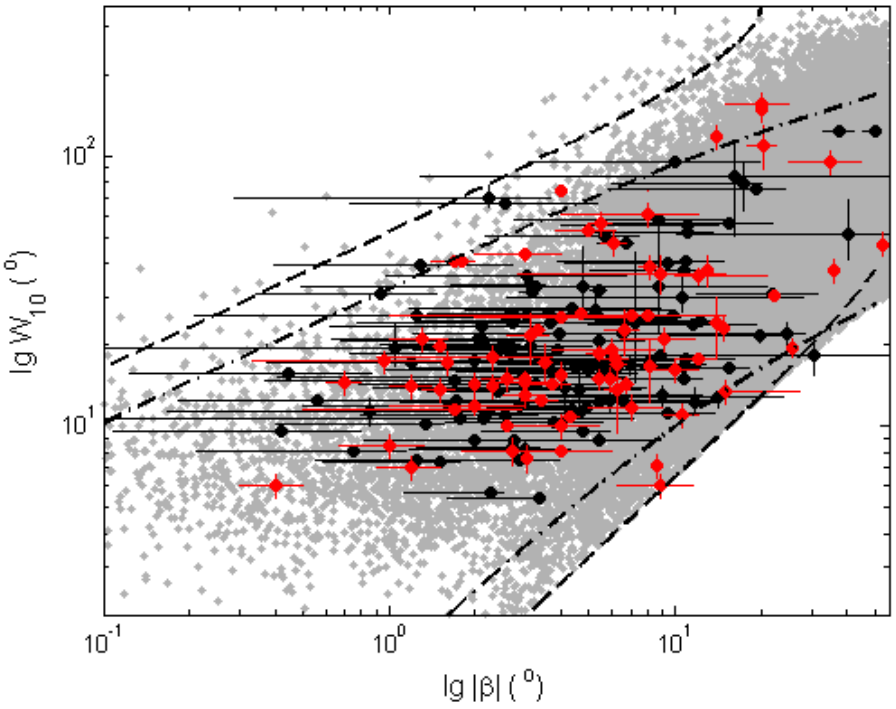
Conal beam



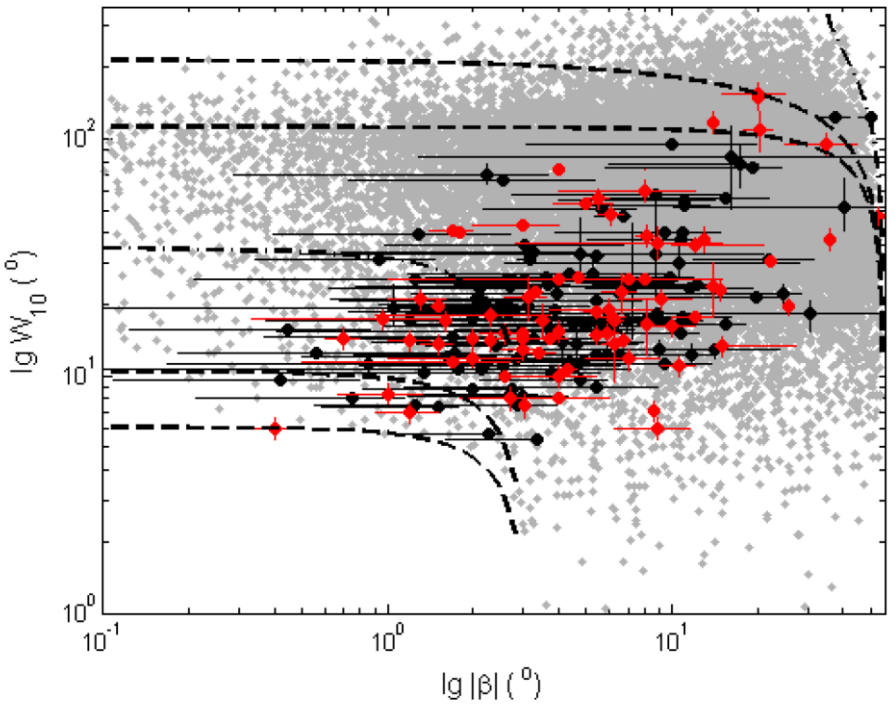
64 pulsars Wang et al.. 2014 ApJ

Updated results

Fan beam

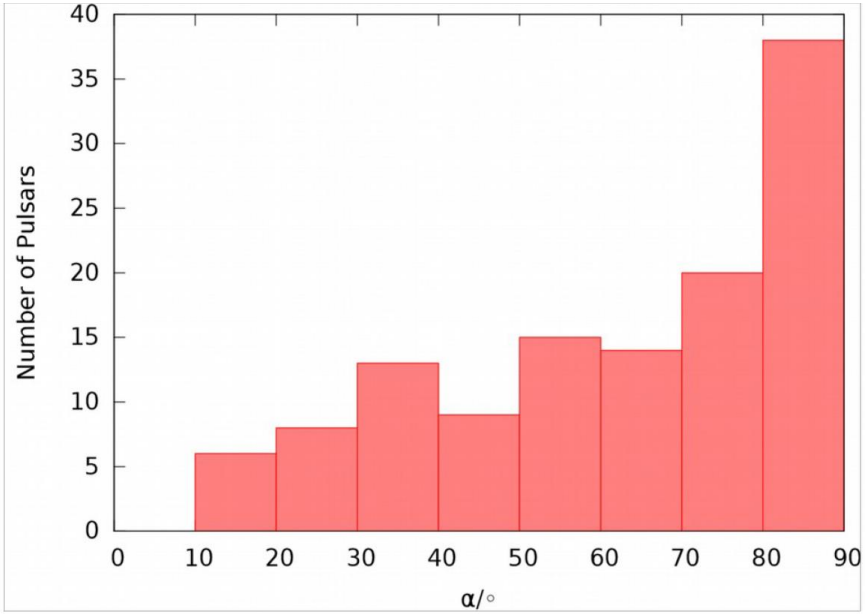


Conal beam

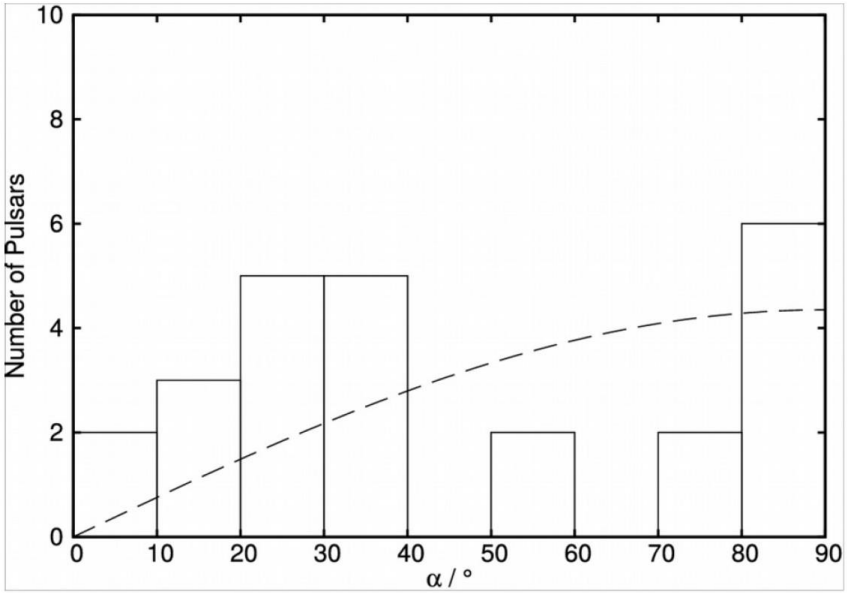


199 pulsars, Chen et al. In preparation

Statistics of the inclination angle



123 pulsars, Chen et al. in preparation



Rookyard et al. 2015

3. Other work

Population studies

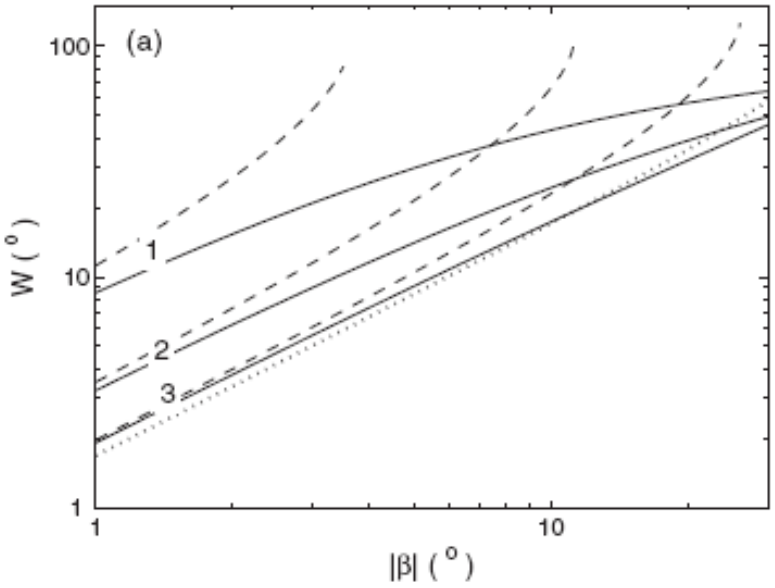
The conal beam model is widely used in population studies of pulsars, e.g. globular cluster, gamma-ray pulsars, and in the studies on the detection capability of pulsars for SKA, FAST.

The fan beam model can be used instead.

Pulse width – impact angle relationship

$$\cos\left(\frac{W}{2}+C\right)=\frac{\sin\alpha}{\tan(\alpha+\beta)(\cos^2\alpha+\tan^{-2}\varphi)^{1/2}}$$

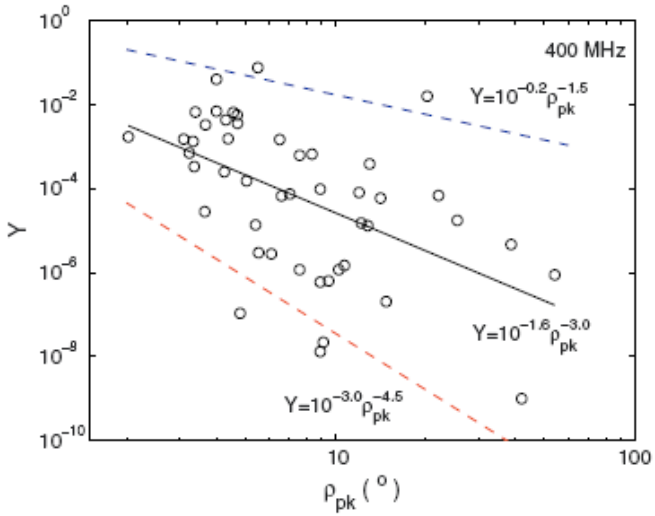
$$C=\arctan(\sec\alpha/\tan\varphi)$$

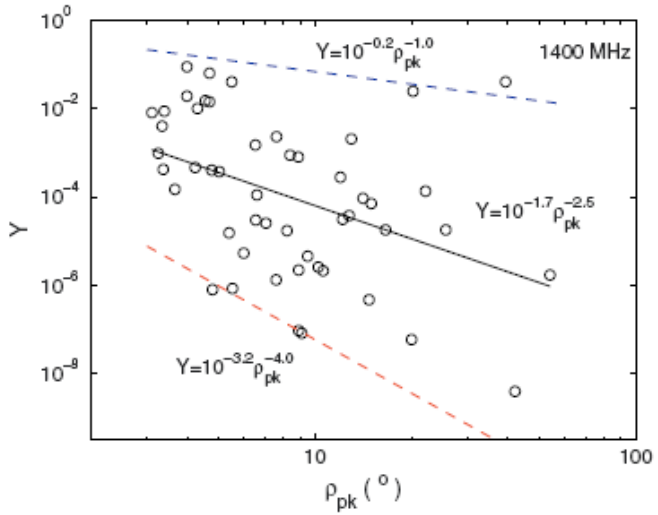


Intensity-radius relationship

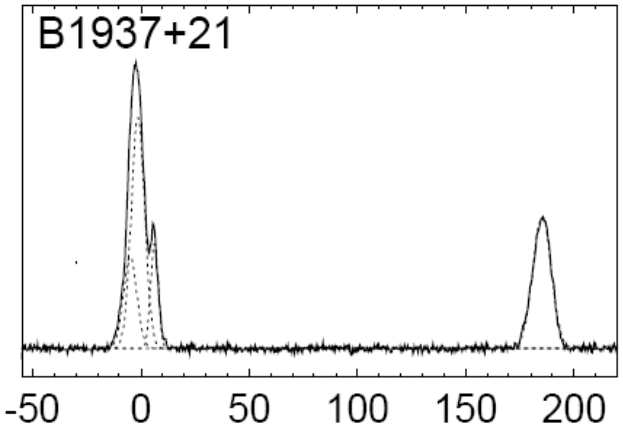
$$I_{\rm outer}^{400\,{\rm MHz}} = 10^{27.2\pm1.4}\, P^{-1.50\pm0.75} \times \dot{P}_{-15}\rho_{\rm peak}^{-3.0\pm1.5}\ {\rm erg\ s^{-1}\ MHz^{-1}\ sr^{-1}}$$

$$I_{\rm outer}^{1400{\rm MHz}} = 10^{25.7\pm1.5}\, P^{-2.25\pm0.75} \times \dot{P}_{-15}\rho_{\rm peak}^{-2.5\pm1.5}\ {\rm erg\ s^{-1}\ MHz^{-1}\ sr^{-1}}$$

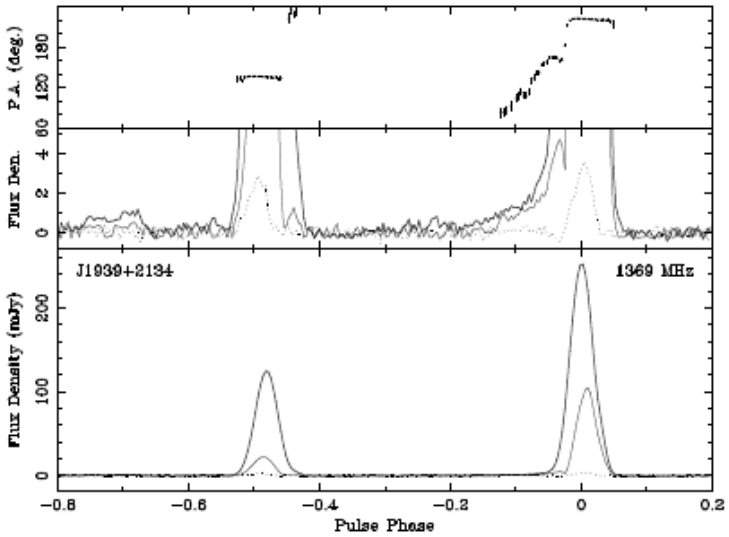




Searching for weak components in averaged pulse profiles

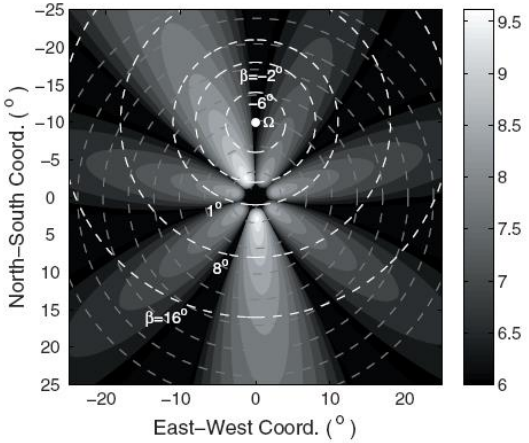


Kramer et al. 1998



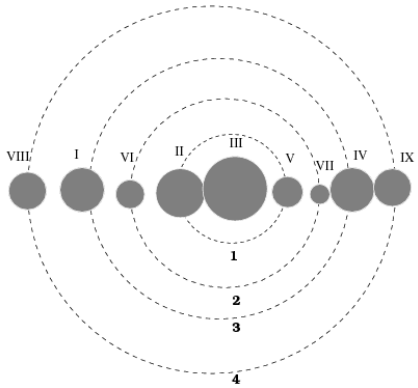
Yan et al. 2011 Dai et al. 2015

Fan beam

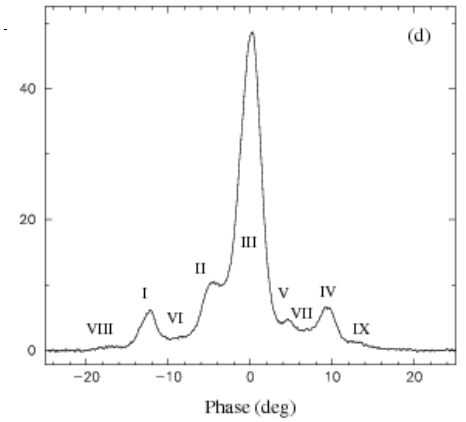


Wang et al. 2014

Conal beam



B0329+54



Gangadhara & Gupta 2001

Summary

- Radio emission beam models can be tested through both statistical and case studies.
- Need high-sensitivity observations