PULSAR RADIO EMISSION ALTITUDE

R. T. Gangadhara

Collaboration: Y. Gupta, Vinod Krishan, Joanna Rankin, Simon Johnston

Student: Reji Mathew C. Thomas

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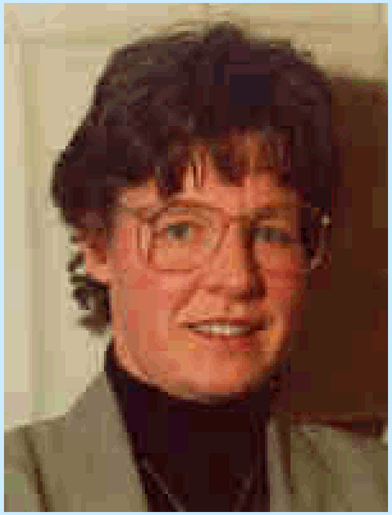
DISCOVERY

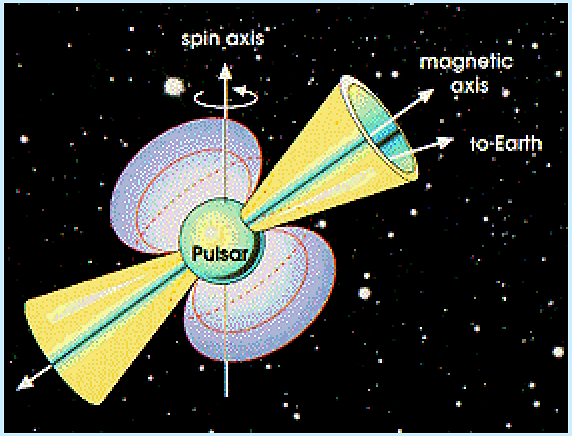


- First detected by Antony Hewish and Jocelyn Bell in 1967.
  - graduate student in England
- An odd radio signal with a rapid pulse rate of one burst per 1.33 seconds.
- More pulsating radio sources were discovered and eventually were named **pulsars.**
- **No clue what they were!**

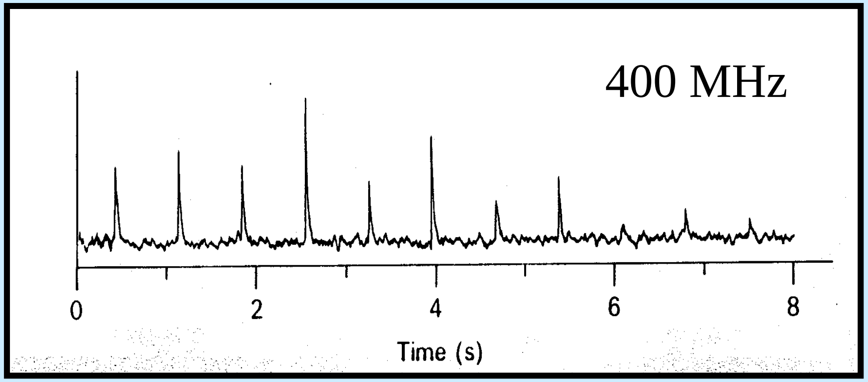
When pulsars were first discovered, it was thought they might be evidence of other intelligent life in the Galaxy

Lighthouse Model

"The pulsars emit beams of radio light. As the pulsar rotates, the beams sweep across the sky. When the beam "sweeps" over Earth, we detect the radiation, as a 'pulse.' "



PSR B0329+54



- Spin period: 1 second to a few millisecond.

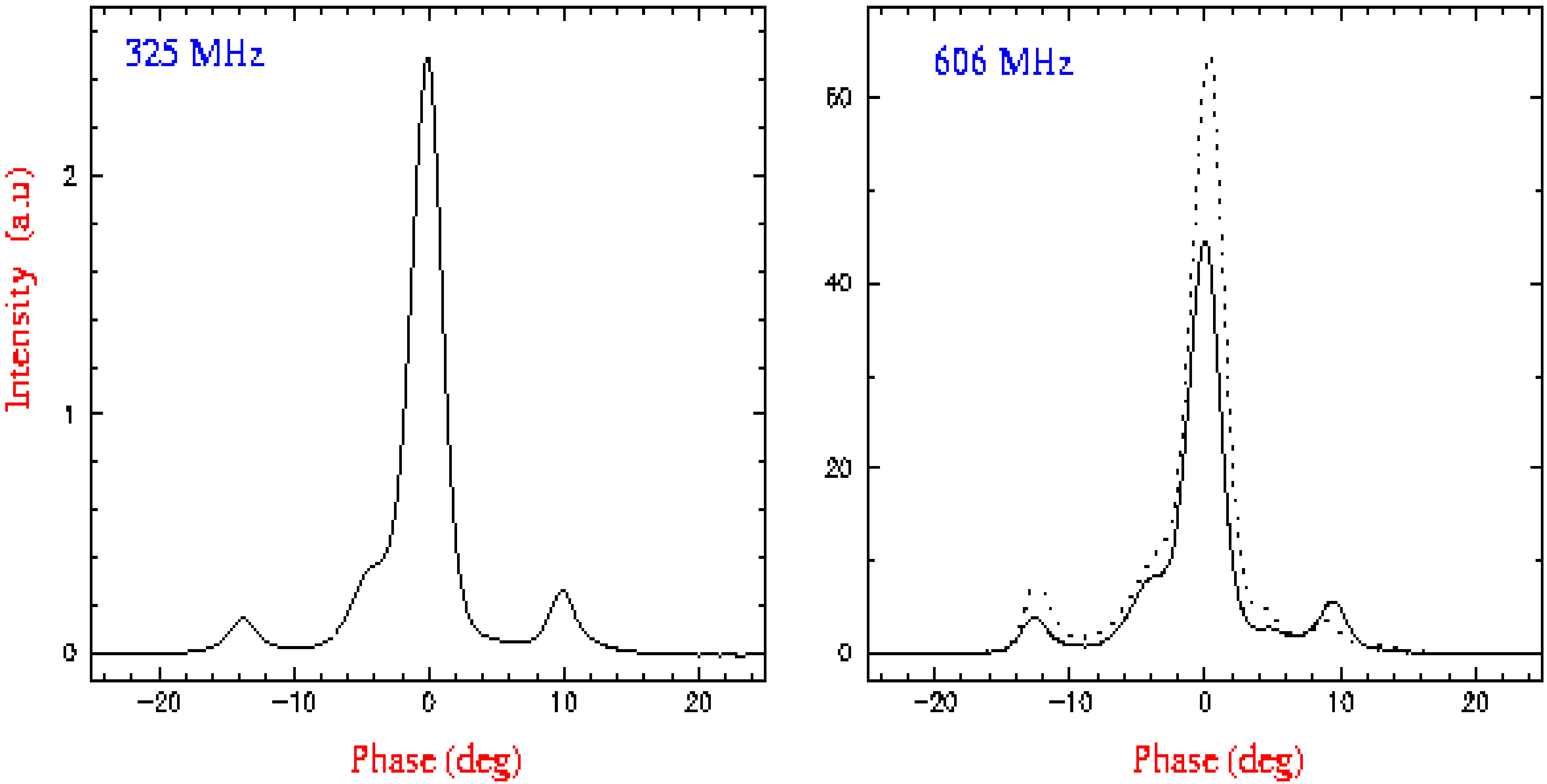
  Rotation effects are significant.

- Dipole Magnetic field: $10^8 - 10^{12} G$

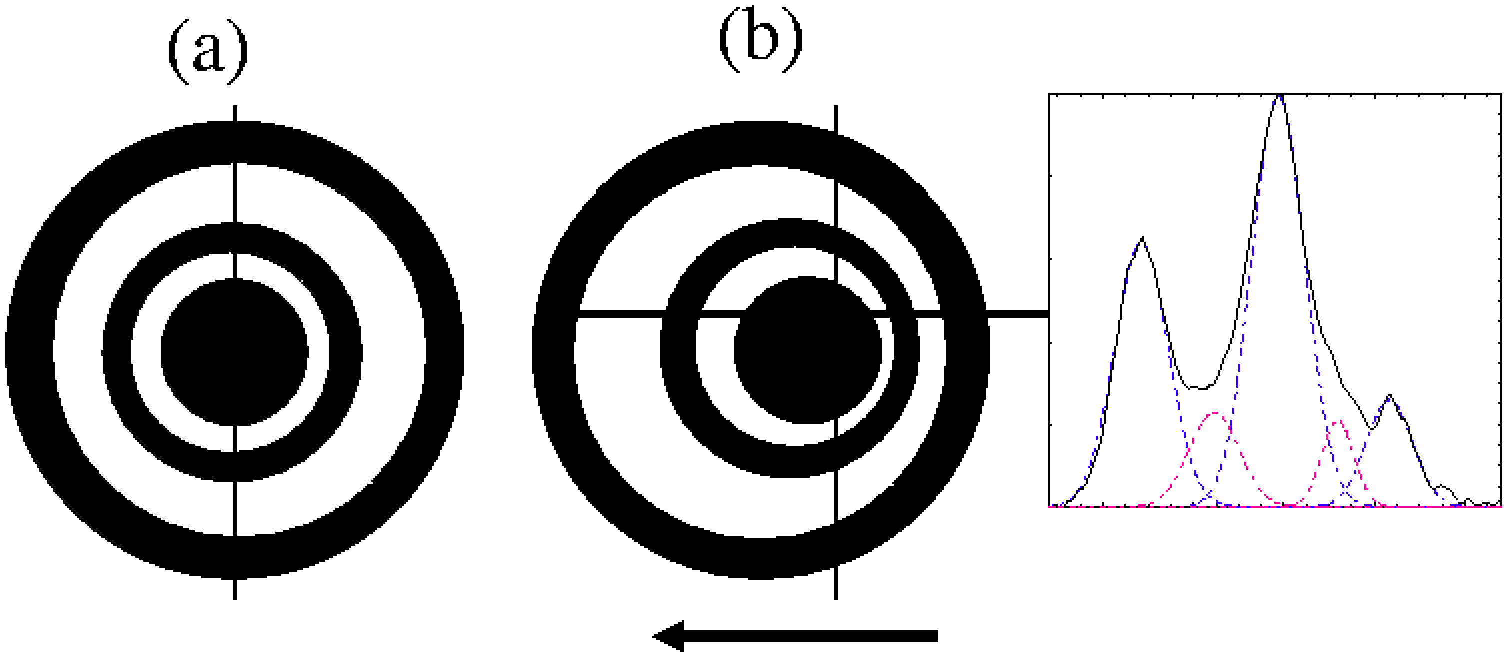
- Coherent radio emission:

  Curvature radiation?

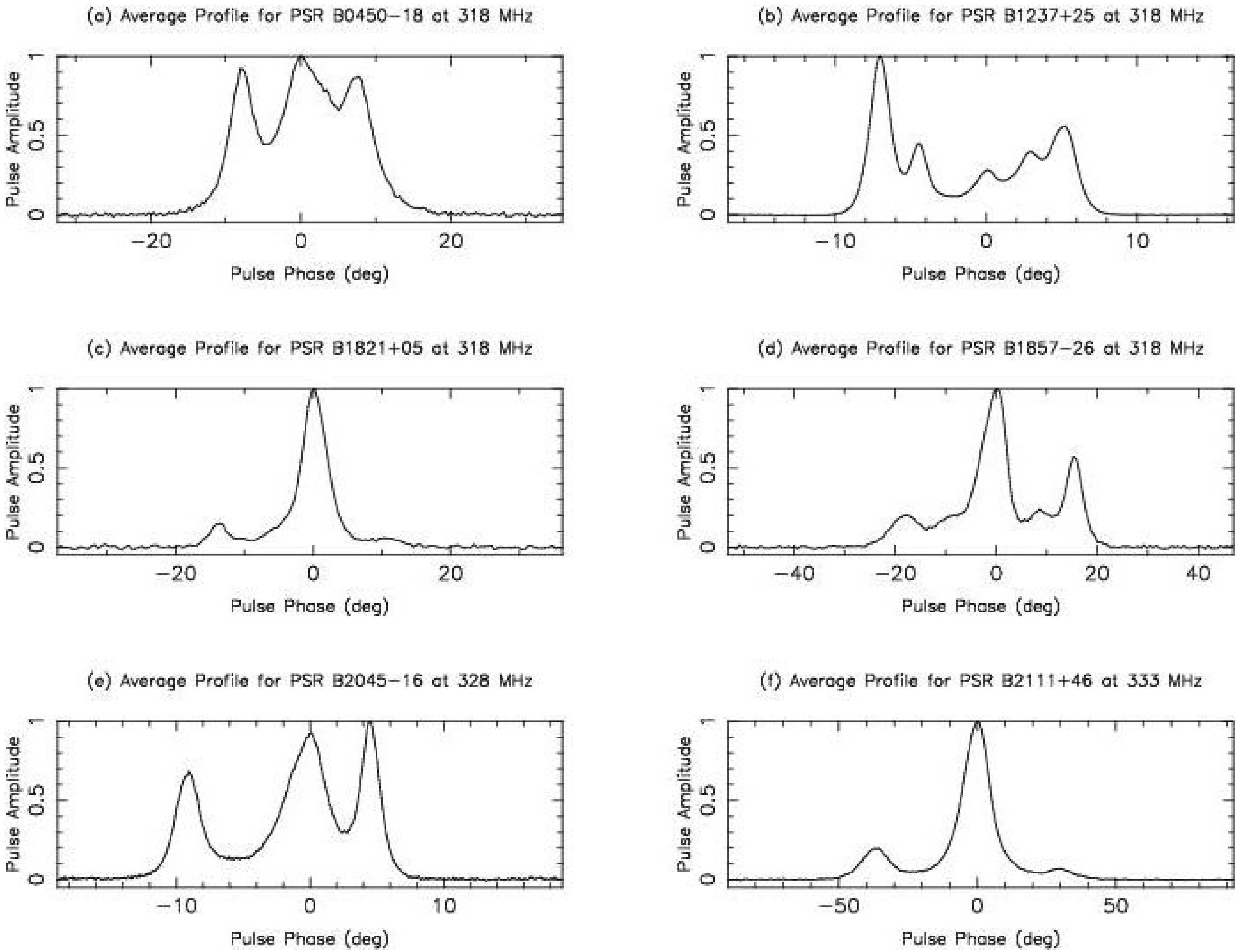
Integrated pulse profiles of PSR B0329+54 P = 0.71 s



Gangadhara, R. T. & Gupta, Y., 2001, ApJ, 555, 31



(a)
(b)

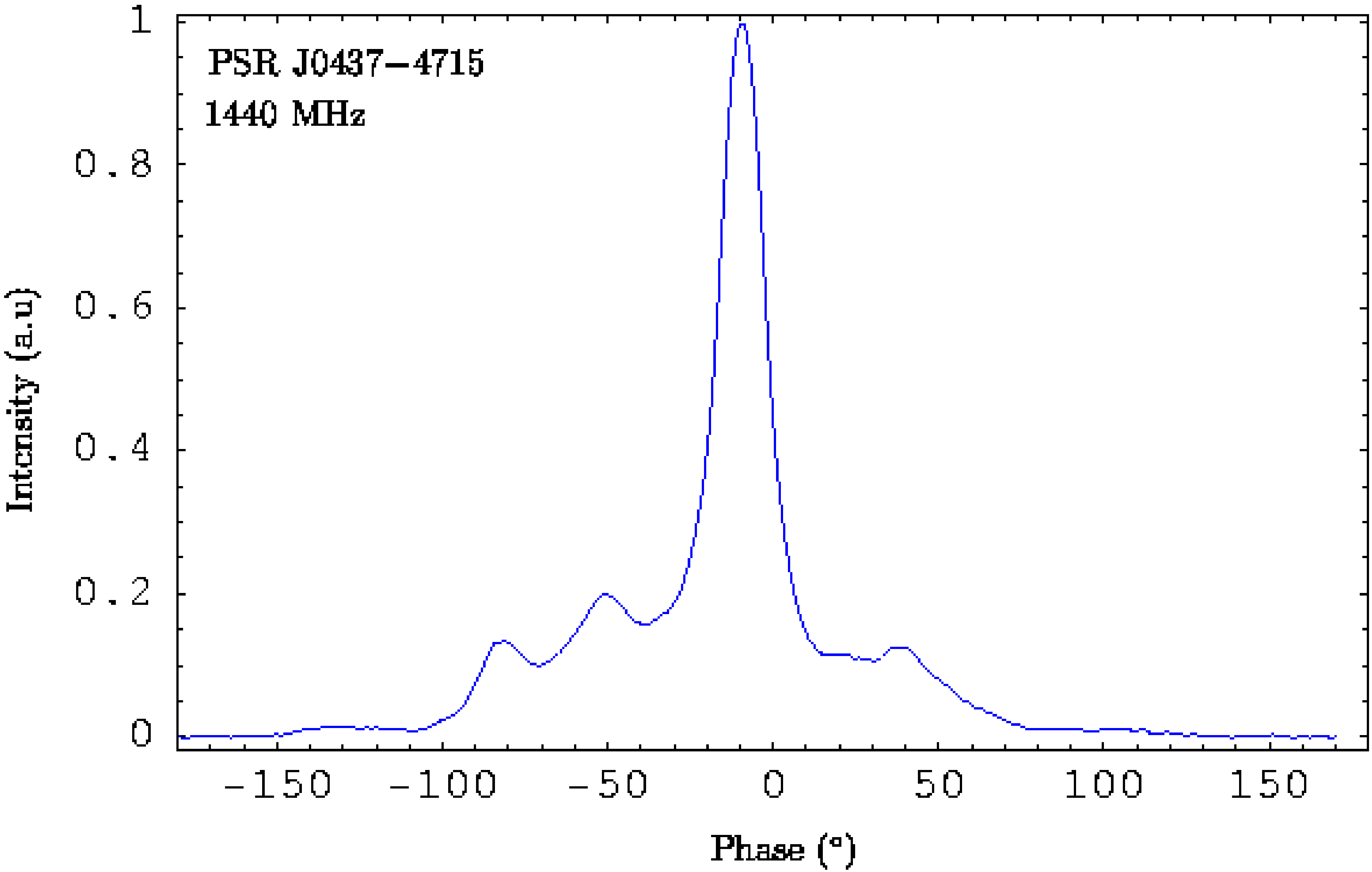


Gupta, Y. & Gangadhara, R. T. , 2003, ApJ, 584, 418

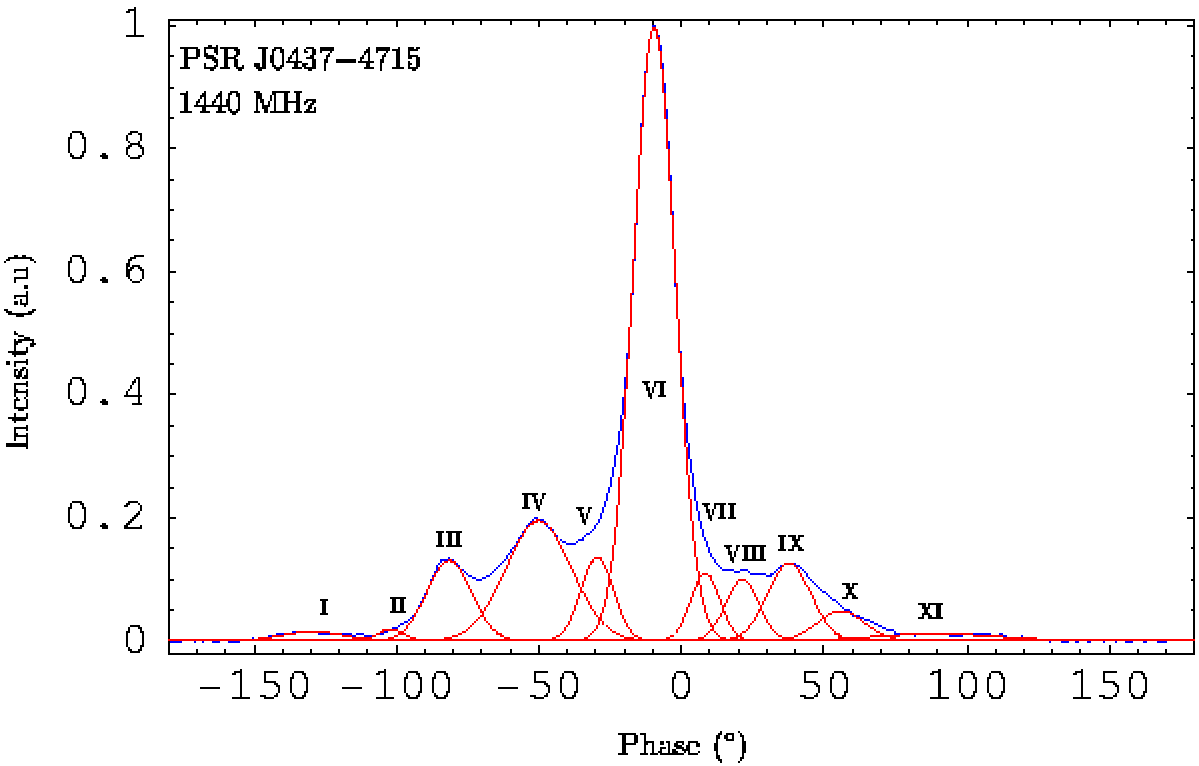
MILLISECOND PULSAR:
PSR J0437-4715

Discovered in Parks by Johnston et al. (1993).

- Nearest and bright millisecond pulsar (~180 pc)
- Spin period 5.75 ms
- Has a low mass white dwarf in binary with orbital period 5.74 days



Data by Johnston and Manchester (2005) from Parks.



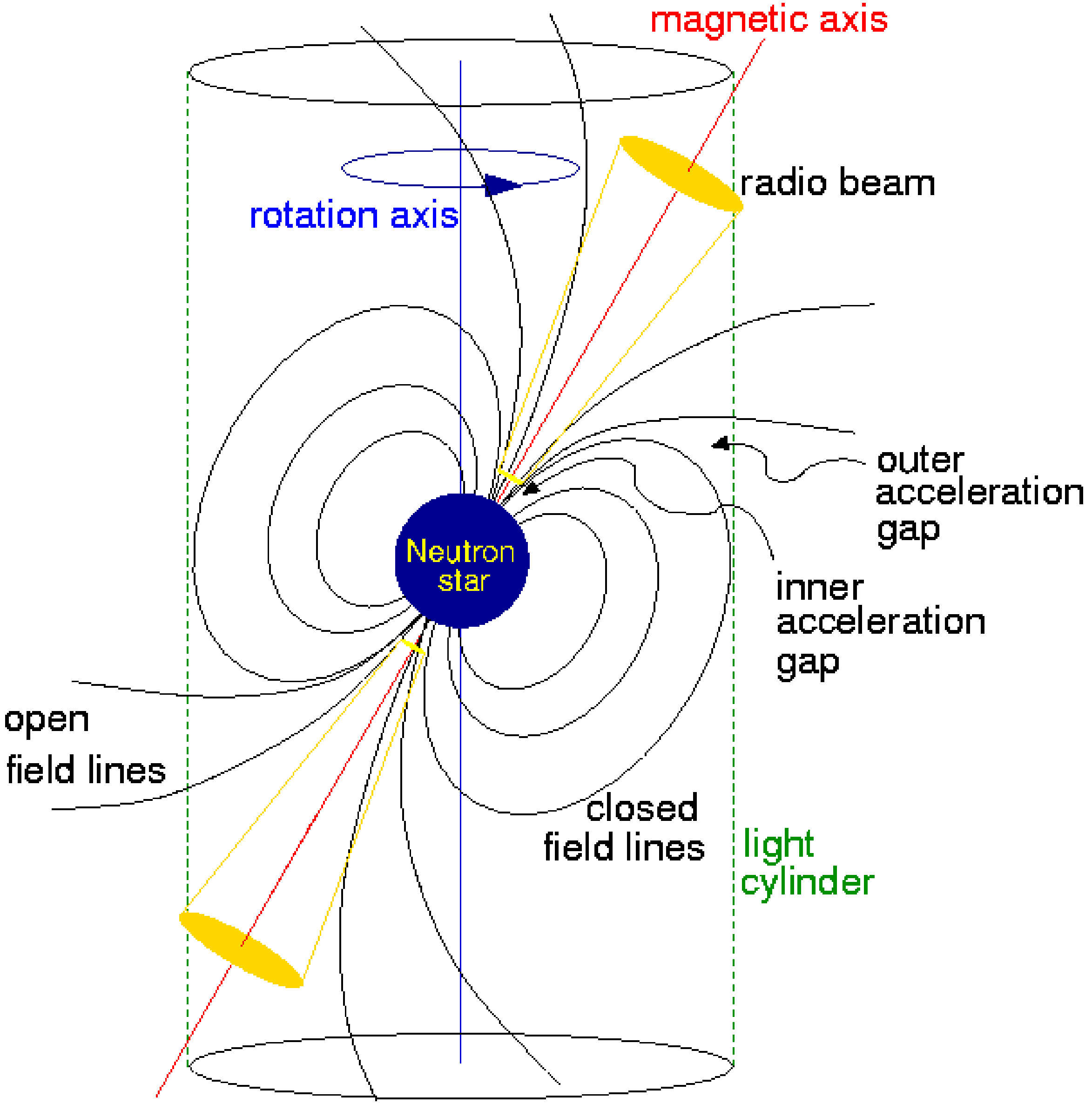
Component locations in PSR J0437−4715 at 1440 MHz

Cone No.	ϕ'_L (deg)	ϕ'_T (deg)	$\delta\phi'$ (deg)
0	—	—	-9.50 ± 0.26
1	-29.50 ± 0.24	8.50 ± 0.46	-10.50 ± 0.26
2	-50.00 ± 0.50	21.50 ± 0.54	-14.25 ± 0.37
3	-81.50 ± 0.15	37.94 ± 0.08	-21.78 ± 0.08
4	-102.01 ± 0.36	56.14 ± 0.29	-22.90 ± 0.23
5	-129.50 ± 1.01	89.54 ± 4.15	-19.98 ± 2.10

MAGNETOSPHERE

Magnetic dipole

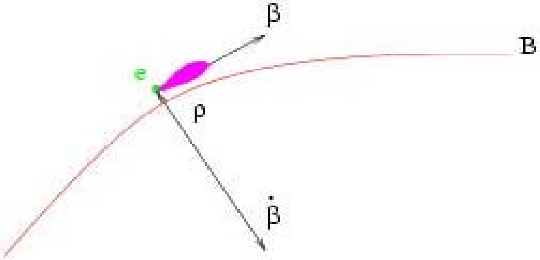
How do they work?



Pulsar Radio Emission

Curvature Radiation

Relatvistic charged particles (e^+, e^-) moving along the curved magnetic field lines experience curvature acceleration, and hence radiate the electromagnetic waves.



The frequency of radiation:

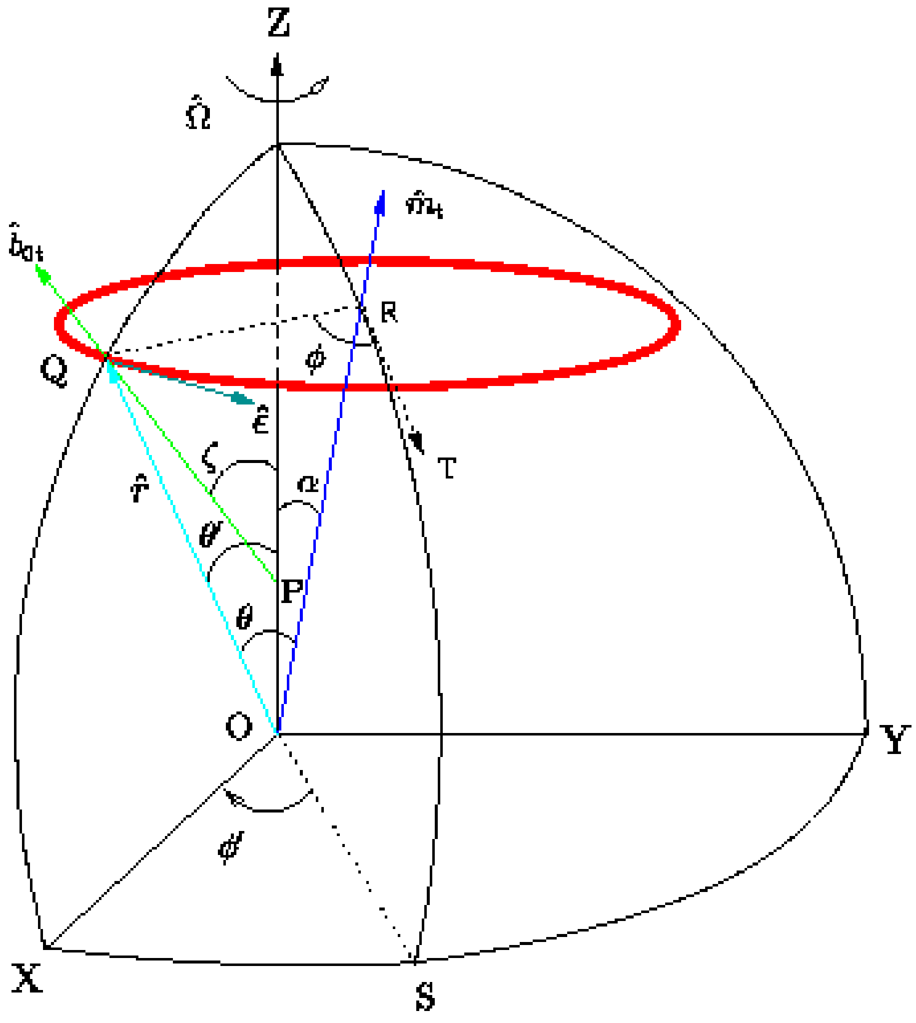
$$\nu_c = \frac{3}{4\pi}\gamma^3\frac{c}{\rho}$$

The power radiated by particles:

$$P = \frac{2}{3}\frac{q^2}{c}\gamma^4\left(\frac{c}{\rho}\right)^2$$

$\rho =$ Radius of curvature of filed lines,
$\gamma = 1/\sqrt{1-\beta^2}$ Lorentz factor.

(Sturrock 1971; Ruderman & Sutherland 1975)



Z
$\hat{\Omega}$
$\hat{m}_t$
$\hat{b}_{0t}$
R
Q
ϕ
$\hat{\epsilon}$
T
ζ
$\hat{r}$
α
θ'
P
θ
O
Y
ϕ'
X
S

COLATITUDE AND AZIMUTH OF EMISSION SPOT

Condition to receive the relativistically beamed emission :

$$\hat{n}.\hat{b}_t = 1$$

$$\hat{n} \times \hat{b}_t = 0$$

Magnetic Colatitude of emission spot :

$$\theta = \frac{1}{2} \arccos\left[\frac{1}{3} \left(\cos\Gamma \sqrt{8 + \cos^2 \Gamma} - \sin^2 \Gamma\right) \right]$$

Magnetic Azimuth of emission spot :

$$\phi = \arctan\left[\frac{\sin\zeta \sin\phi'}{\cos\zeta \sin\alpha - \cos\alpha \sin\zeta \cos\phi'} \right]$$

Gangadhara, R. T. , 2004, ApJ, 609, 335

EMISSION ALTITUDE FROM PHASE SHIFT

- Aberration
- Retardation
- Polar cap current

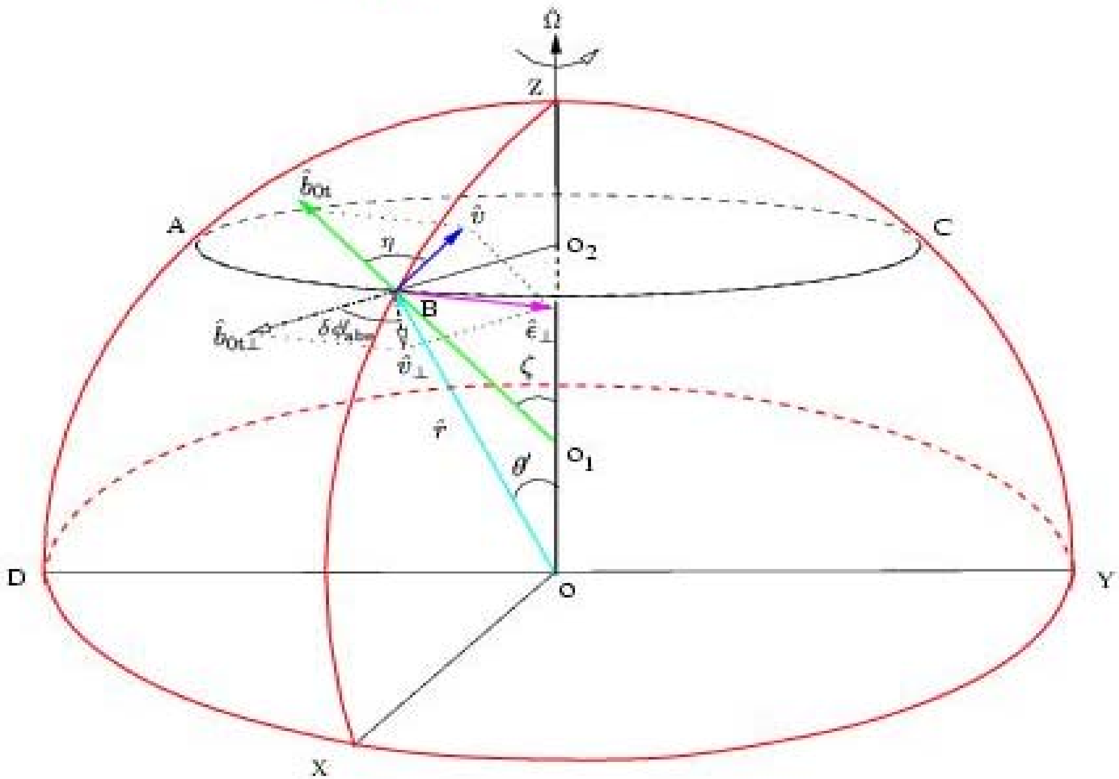
ABERRATION PHASE SHIFT

The velocity of plasma particle (bunch):

$$\mathbf{v} = \kappa c \widehat{b}_{0\text{t}} + \mathbf{v}_{\text{rot}}$$

Rotation velocity:

$$\mathbf{v}_{\text{rot}} = \boldsymbol{\Omega} \times \mathbf{r} = \Omega r \sin\theta' \,\widehat{\epsilon}$$



Aberration Angle

$$\tan\eta = \frac{\Omega r}{c}\frac{\sin\theta'\sin\Theta}{\sqrt{1-(\Omega r/c)^2\sin^2\theta'\sin^2\Theta}}.$$

Aberration Phase Shift

$$\cos(\delta\phi'_{\rm abe}) = \widehat{v}_\perp\cdot\widehat{b}_{\rm 0t\perp}$$

$$= \tan\zeta\cot\psi + \frac{\Omega r}{c}\frac{\sin\theta'\cos\Theta}{\sin\zeta\sin\psi}.$$

where

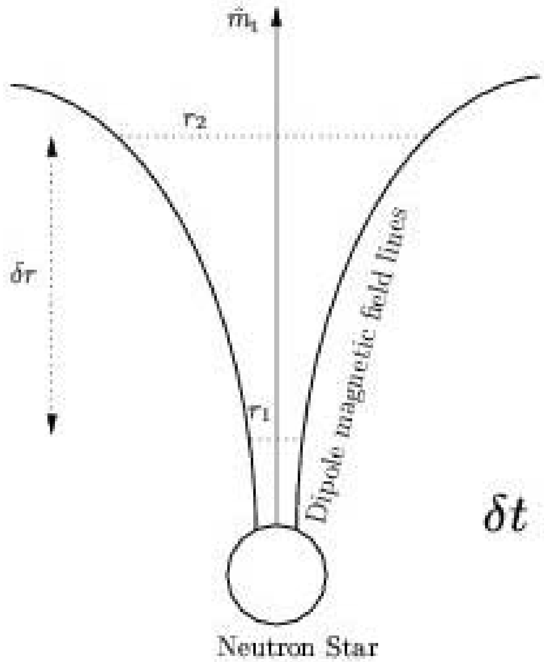
$$\cos\psi = \widehat{\Omega}.\widehat{v}$$

$$= \cos\zeta\left(\sqrt{1-\left(\frac{\Omega r}{c}\right)^2\sin^2\theta'\sin^2\Theta} - \frac{\Omega r}{c}\sin\theta'\cos\Theta\right).$$

Dykes, Rudak and Harding (2004, ApJ, 607, 939):

$$\delta\phi'_{\rm abe} = \frac{\Omega r}{c}$$

RETARDATION PHASE SHIFT



$$t_1 = \frac{1}{c}(d - \mathbf{r}_1 \cdot \widehat{n})$$

$$t_2 = \frac{1}{c}(d - \mathbf{r}_2 \cdot \widehat{n})$$

Time delay:

$$\delta t = t_1 - t_2 = \frac{1}{c}(\mathbf{r}_2 \cdot \widehat{n} - \mathbf{r}_1 \cdot \widehat{n}).$$

$$\delta t = \frac{r}{c}(\widehat{r} \cdot \widehat{n}).$$

Retardation Phase Shift:

$$\delta\phi'_{\mathrm{ret}} = \Omega \delta t = \frac{\Omega r}{c} \cos\sigma \ .$$

EMISSION ALTITUDE FROM PHASE SHIFT

Net phase shift:

$$\begin{aligned} \delta\phi' &= \delta\phi'_{\rm abr} + \delta\phi'_{\rm ret} + \delta\phi'_{\rm pc} \\ &= r_{\rm n}\cos\sigma + \cos^{-1}\left[\tan\zeta\cot\psi + \frac{\Omega r}{c}\frac{\sin\theta'\cos\Theta}{\sin\zeta\sin\psi}\right] \\ &\quad + \tan^{-1}\left[\frac{d_1\, r_{\rm n}}{d_2 + d_3\, r_{\rm n}}\right] \ , \end{aligned}$$

For $\delta\phi' \ll 1$, we obtain

$$r = \frac{r_{\rm LC}}{\nu_1}\delta\phi' + O(\delta\phi')^2,$$

where

$$\nu_1 = \csc^2\zeta\sin\theta'\sqrt{-\cos(\Theta-\zeta)\cos(\Theta+\zeta)} +$$

$$\cos(\Gamma - \theta) + (d1/d2)$$

(Gangadhara, R. T., 2005, ApJ, 628, 923)

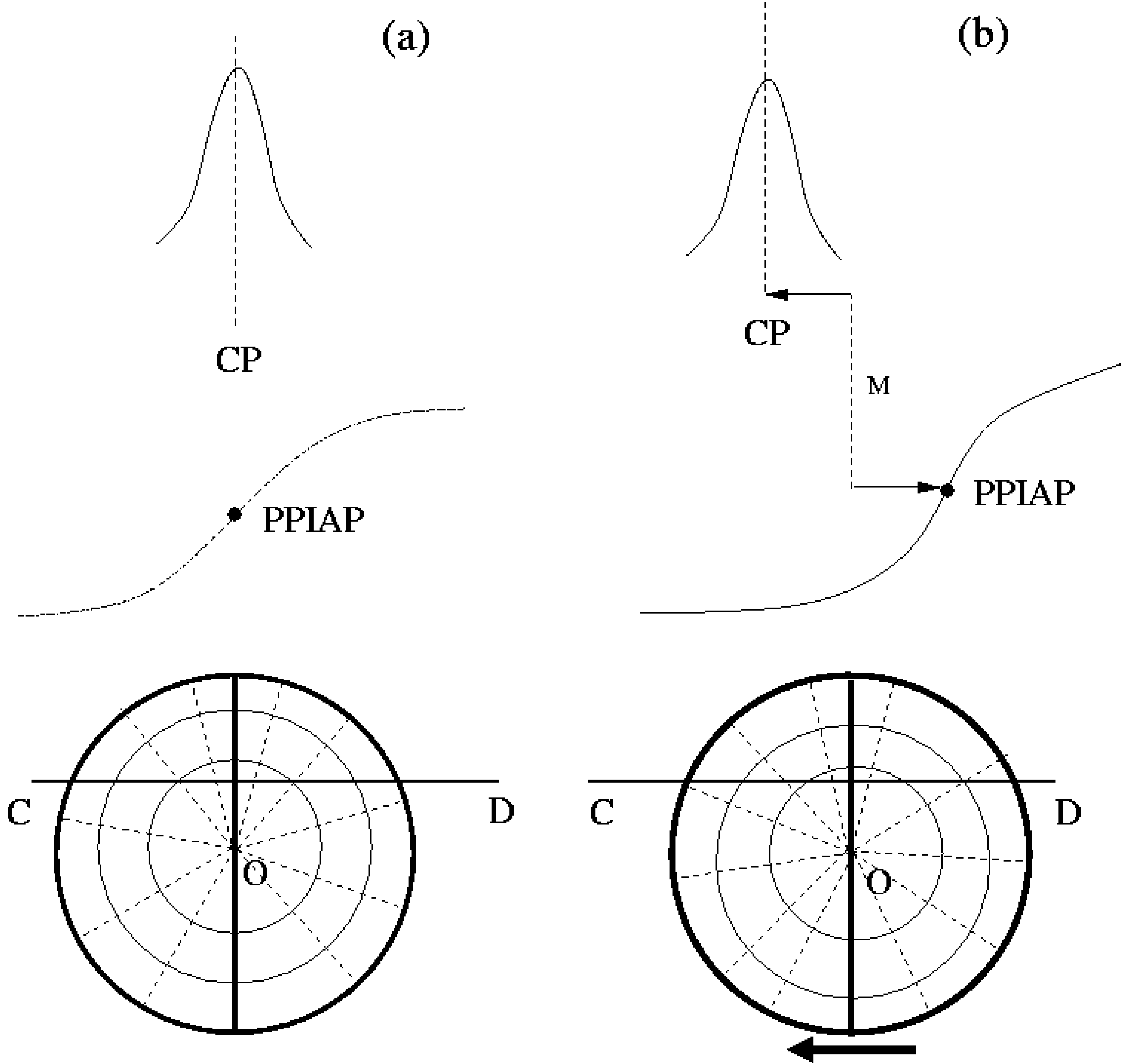
POLARIZATION ANGLE

Radhakrishnan and Cooke (1969) proposed "Pulsar radiation is polarized in the direction of curvature of mag. field lines."

Blaskiewicz, Cordes and Wasserman (1991) derived the expression for PA by taking into account of aberration at constant emission height.

$$\psi = \arctan\left[\frac{\sin\alpha\sin\phi' - 3(r/r_{\rm LC})\sin\zeta}{\sin\beta + \sin\alpha\cos\zeta(1-\cos\phi')}\right]$$

Dyks, Rudak and Harding (2004) have proposed "Intensity profile Advances and PA inflection point delays by equal amount when we include retardation.



(a)
CP
PPIAP
C
D
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(b)
CP
M
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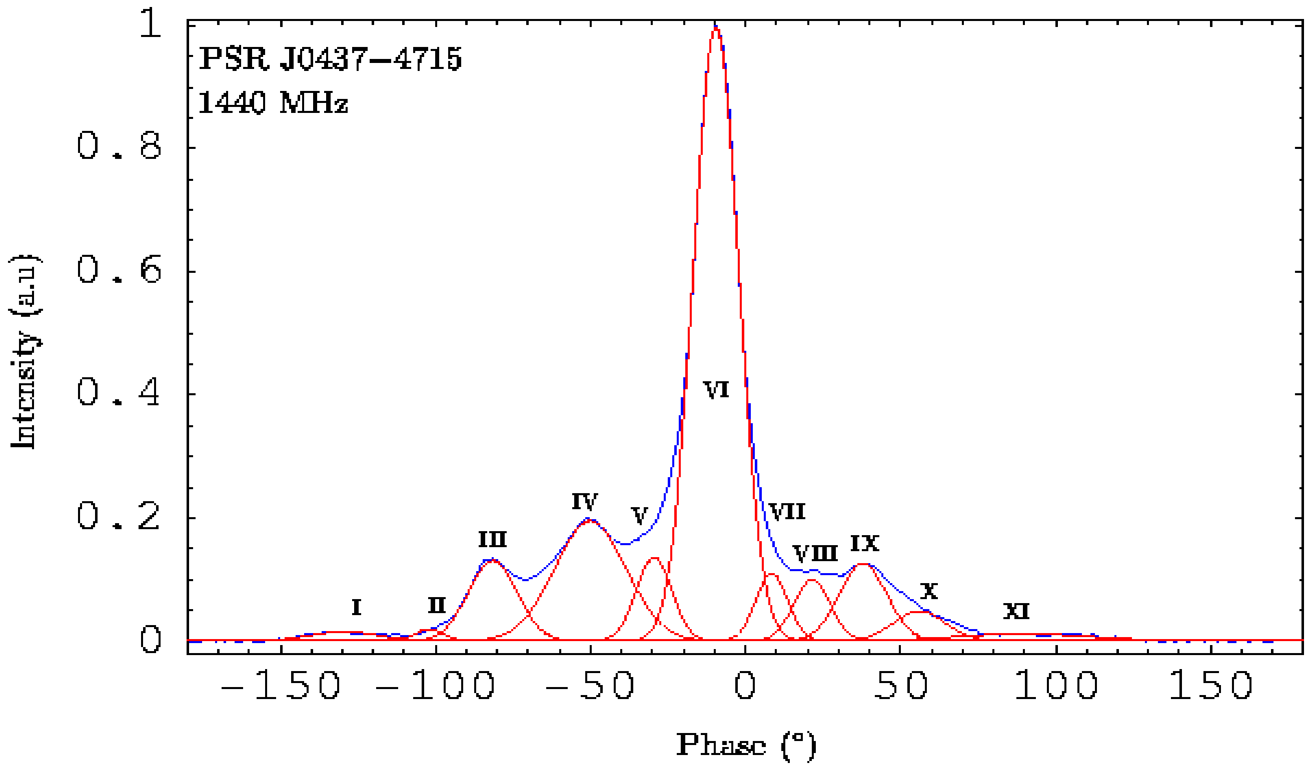

Emission altitudes in PSR J0437−4715 at 1440 MHz

Cone No.	(Km)	r_{em} (Km)	($\%r_{LC}$)	$\Delta(\%)$	S/S_{lof}
0	—	20.3±0.6	7	12	0.17±0.00
1	25.2	23.3±0.5	9	8	0.28±0.01
2	34.2	34.3±0.9	13	0	0.38±0.01
3	52.2	64.3±0.3	23	19	0.43±0.00
4	55.0	84.9±0.9	31	35	0.47±0.00
5	48.0	91.8±6.2	33	49	0.57±0.02

DRH04 G05

(Gangadhara, R. T., 2006, ApJ, Submitted)

CONCLUSION

- Developed a method for estimating the absolute emission heights of core as well as conal components.

In millisecond pulsar: J0437-4715

(i) A/R phase shift is quite high (~20 deg).

(ii) Core component is emitted from an altitude close to NS surface (~20 Km).

(iii) Emission altitude of cones increases from core to outer most cone (~90 Km).

(Gil & Krawczyk 1997)