脉冲星的辐射区域（概论）

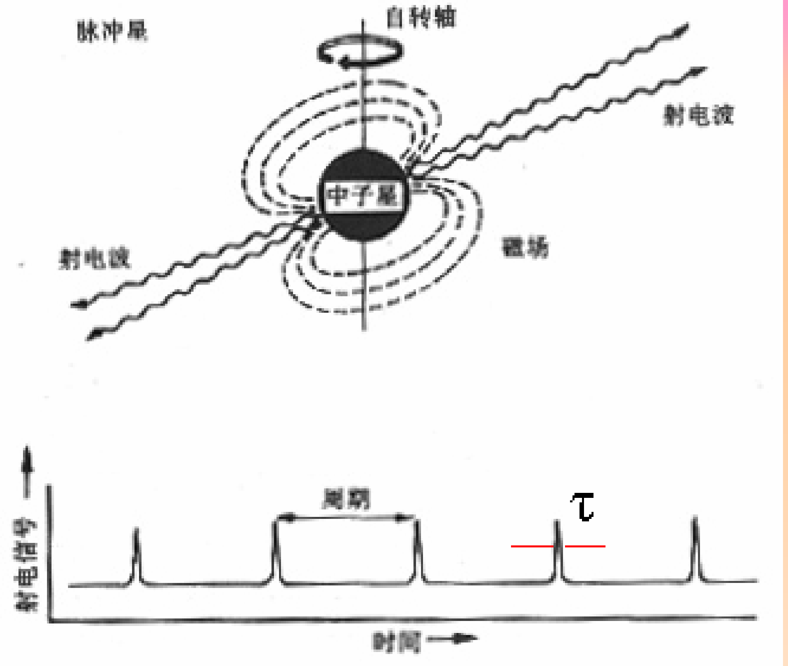
一、观测提供的信息

二、脉冲星的磁层结构和可能的加速电势

三、加速区的可能部位

四、加速区、辐射区有关的讨论

脉冲宽度



- 脉冲的持续时间和脉冲周期之比在2%到10%之间，典型值为3%，即相当于约10° 的辐射“窗口”。脉冲宽度与脉冲周期强相关。已知的脉冲周期跨越3个数量级，但不同周期的脉冲星的辐射“窗口”宽度则是相当靠近的，几乎与周期无关。

射电脉冲星辐射部位

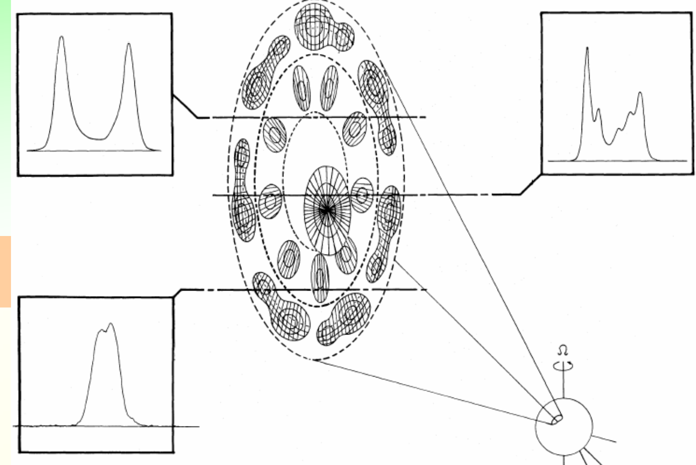
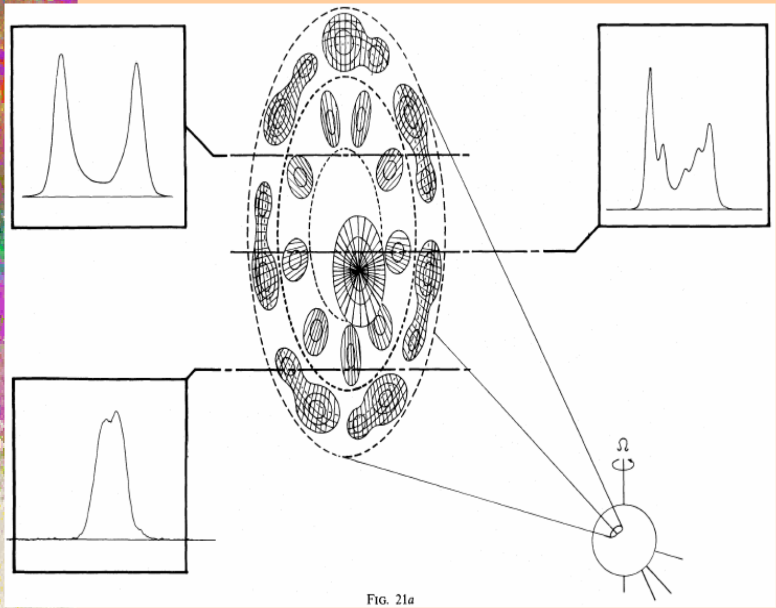


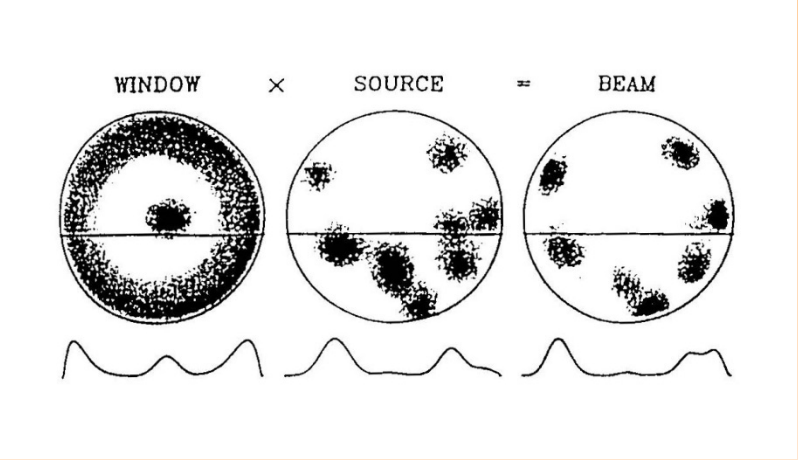
Fig. 21a

Rankin, 1983, ApJ,274,333

中心辐射束在靠近磁轴的中心部位，空心辐射束环绕中心辐射束。中心辐射束产生在靠近中心星的表部分，空心辐射来着产生于较高的辐射部位，其高度为100—200km（Rankin, 1993）。空心辐射束有内环和外环之分，在1GHz上内环产生的高度约120km，外环产生的高度约210km。

Emission beams





Rankin, 1983,
ApJ,274,333

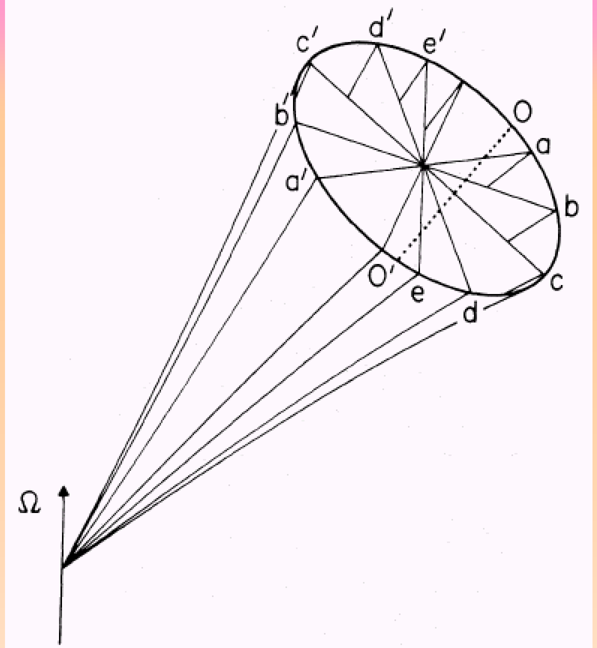
Manchester,R.N. 1995
J. Astroph. Astr. 16,107

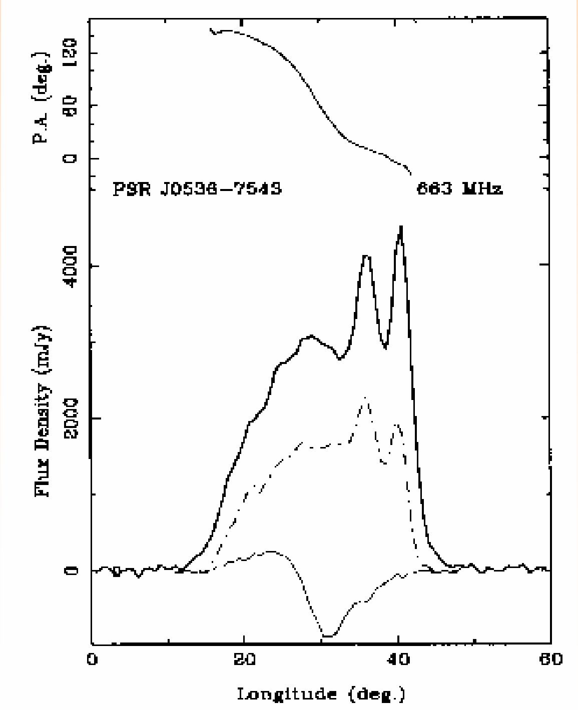
Han & Manchester,2001,MN

偏振

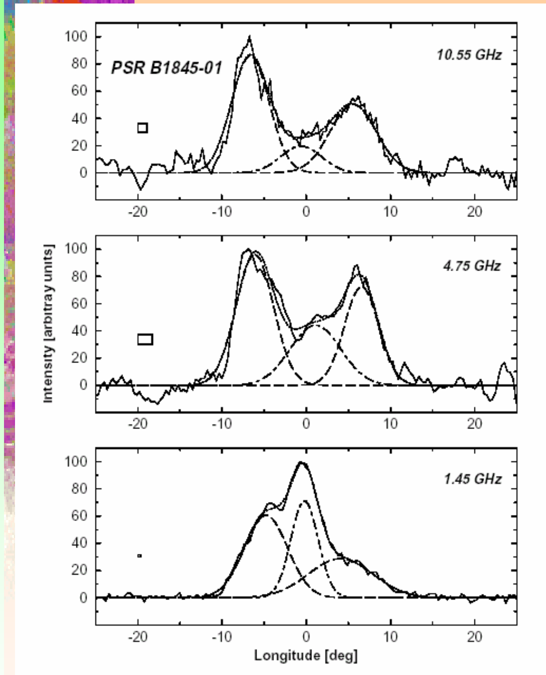
1、有的脉冲星的线偏振度可高达100% --排除了同步辐射机制;

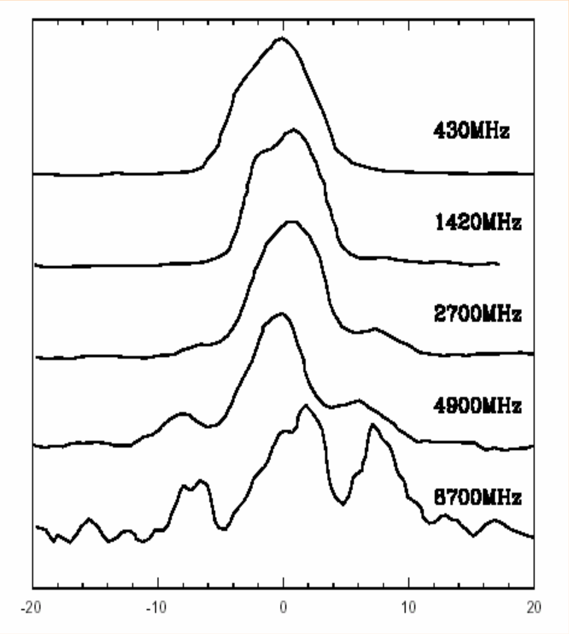
2、线偏振成份的偏振位置角随脉冲经度（相位）而变化，呈“S”型 --支持脉冲星的辐射来自极冠区.

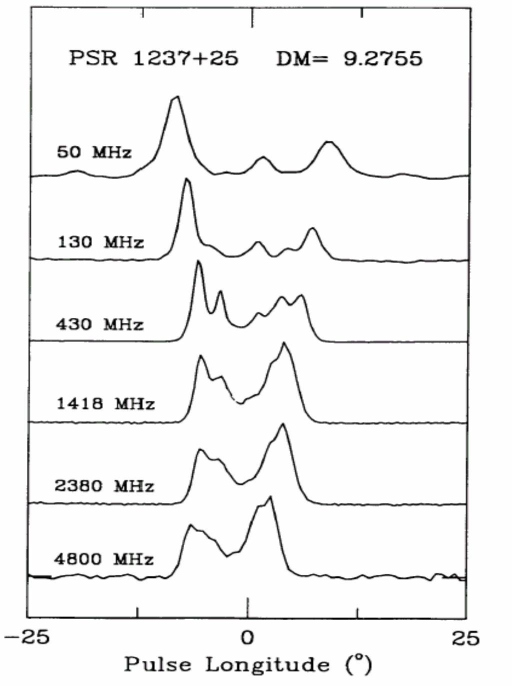


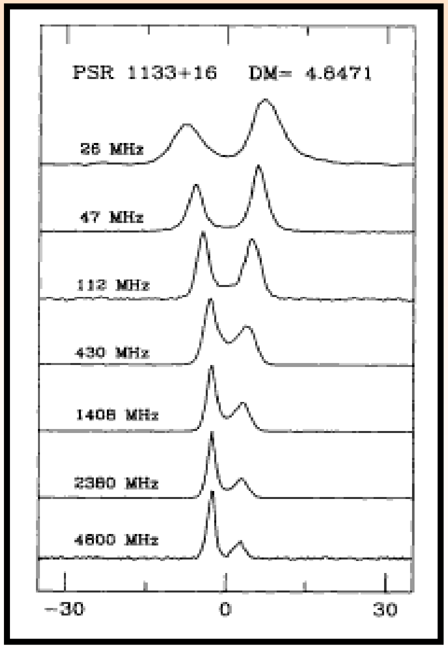


累积脉冲与频率之间的关系



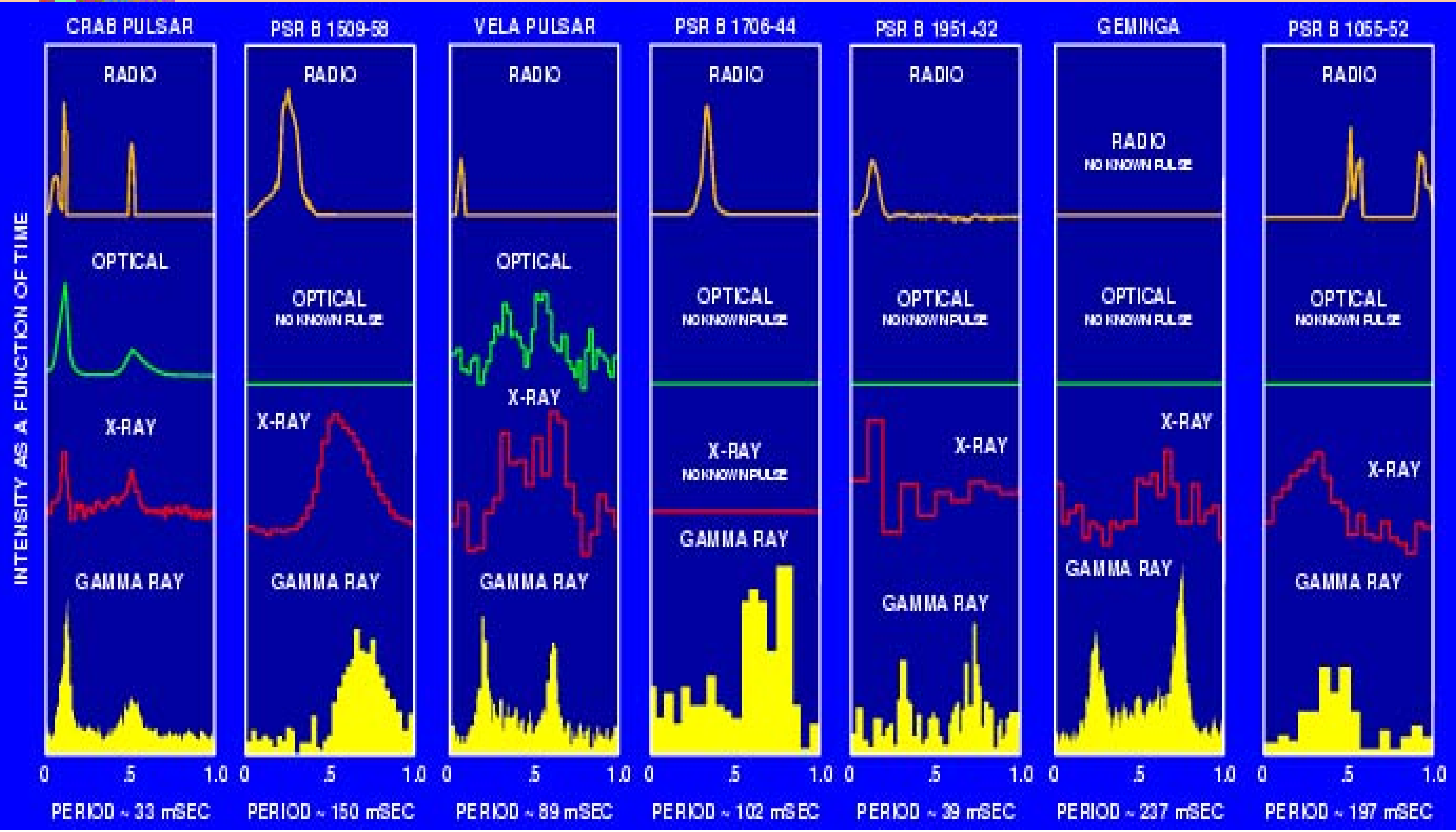






累积脉冲剖面随频率有明显变化

各种频率上的脉冲剖面


INTENSITY AS A FUNCTION OF TIME
CRAB PULSAR
PSR B 1509-58
VELA PULSAR
PSR B 1706-44
PSR B 1951+32
GEMINGA
PSR B 1055-52
RADIO
NO KNOWN PULSE
OPTICAL
X-RAY
GAMMA RAY
0
.5
1.0
PERIOD ~ 33 mSEC
PERIOD ~ 150 mSEC
PERIOD ~ 89 mSEC
PERIOD ~ 102 mSEC
PERIOD ~ 39 mSEC
PERIOD ~ 237 mSEC
PERIOD ~ 197 mSEC

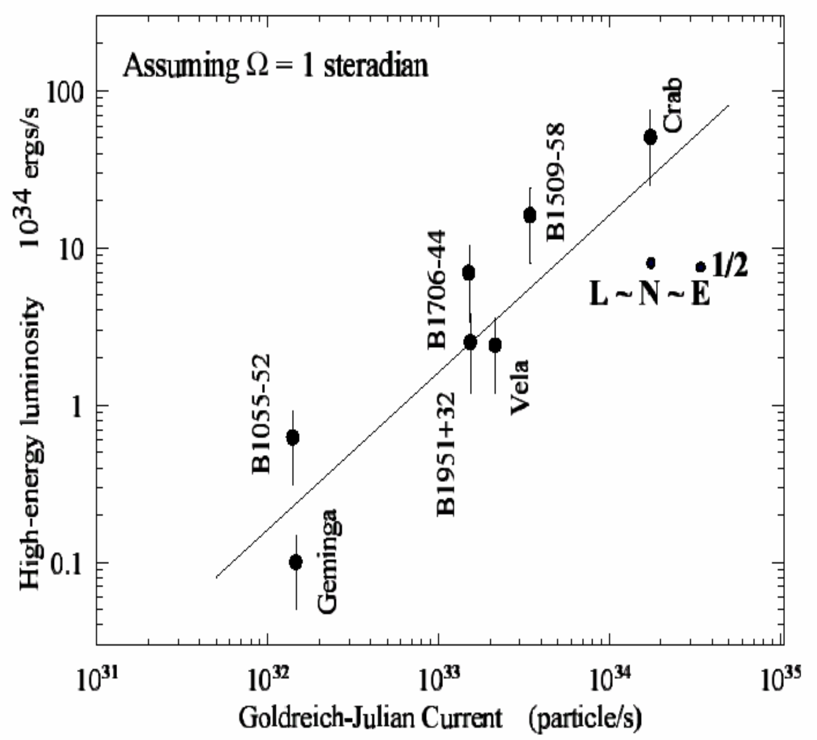
Radio PSR: E_{rot}/dt>L

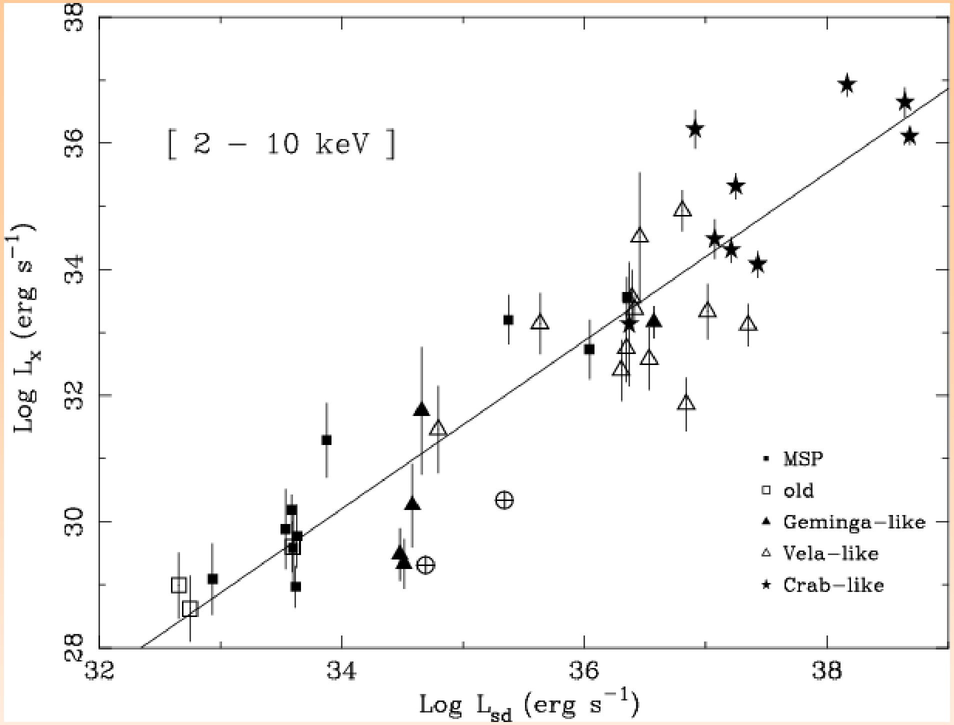
Table 1. Summary Properties of the Highest-Confidence and Candidate Gamma-Ray Pulsars

Name	P (s)	τ (Ky)	$\dot{E}$ (erg/s)	F_E (erg/cm^{2}s)	d (kpc)	L_{HE} (erg/s)	η (E>1 eV)
Crab	0.033	1.3	4.5×10^{38}	1.3×10^{-8}	2.0	5.0×10^{35}	0.001
B1509−58	0.150	1.5	1.8×10^{37}	8.8×10^{-10}	4.4	1.6×10^{35}	0.009
Vela	0.089	11	7.0×10^{36}	9.9×10^{-9}	0.3	8.6×10^{33}	0.001
B1706−44	0.102	17	3.4×10^{36}	1.3×10^{-9}	2.3	6.6×10^{34}	0.019
B1951+32	0.040	110	3.7×10^{36}	4.3×10^{-10}	2.5	2.5×10^{34}	0.007
Geminga	0.237	340	3.3×10^{34}	3.9×10^{-9}	0.16	9.6×10^{32}	0.029
B1055−52	0.197	530	3.0×10^{34}	2.9×10^{-10}	0.72	1.4×10^{33}	0.048
B1046−58	0.124	20	2.0×10^{36}	3.7×10^{-10}	2.7	2.6×10^{34}	0.013
B0656+14	0.385	100	4.0×10^{34}	1.6×10^{-10}	0.3	1.3×10^{32}	0.003
J0218+4232	0.002	460,000	2.5×10^{35}	9.1×10^{-11}	2.7	6.4×10^{33}	0.026

伽玛射线主控着转动能损失！

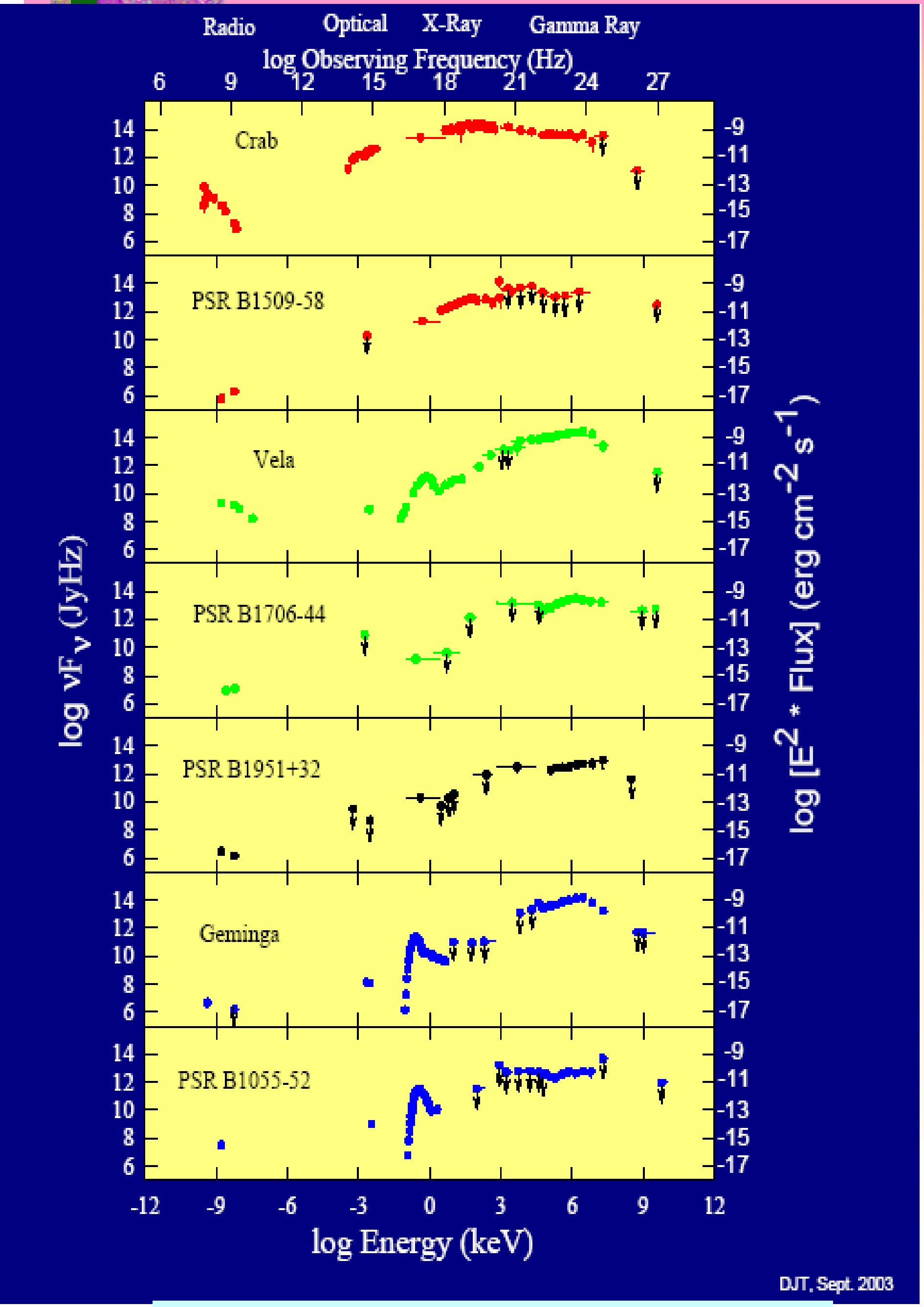
Thompson astro-ph/0312272





Kanbach astro-ph/0209021

Possenti et al (2002)



Thompson, astro-ph/0312272

1. 各相位上频谱有系统变化，bridge 谱最硬

2. 都有高能的 cutoff

3. 频谱范围 10kev — 10Gev

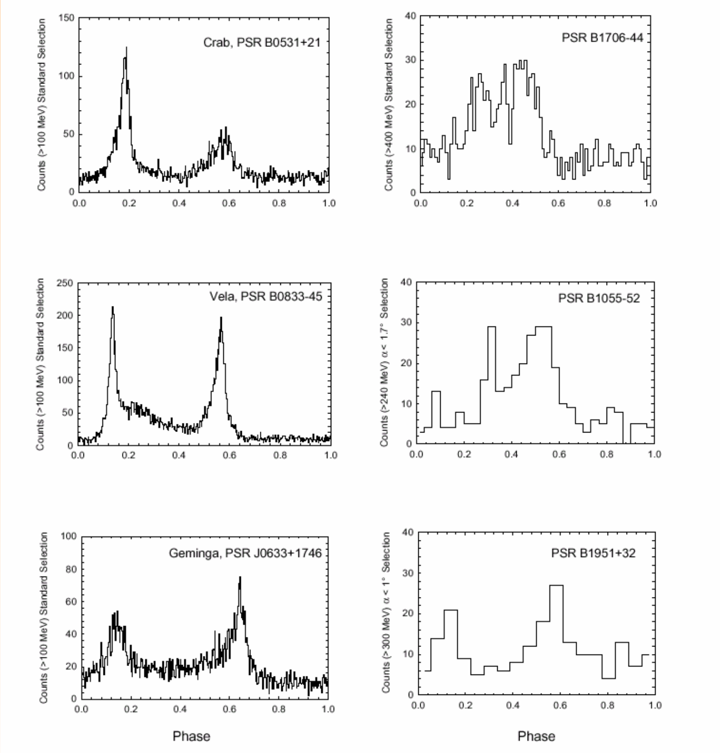


Fig. 2. High-energy light curves of γ-ray pulsars (> 100 MeV, unless indicated differently)

Kanbach, 2002,astro-ph/0209021

伽玛射线脉冲星主要观测特征

(1) two peaks more than 50% of the rotation, i.e. a wide beam of emission;

(2) luminosity maximum around 1 GeV. A spectral cutoff above several GeV;

(3) the spectra vary with rotational phase indicating different sites of emission;

(4) the particle flux from the open regions of the magnetosphere (Goldreich-Julian current).

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中子星的静态磁层：　平行与磁场的电场为零

$F_e = eE = e\,\Omega B R_{NS}/c$

$F_g = GM_{NS}m/R^2$

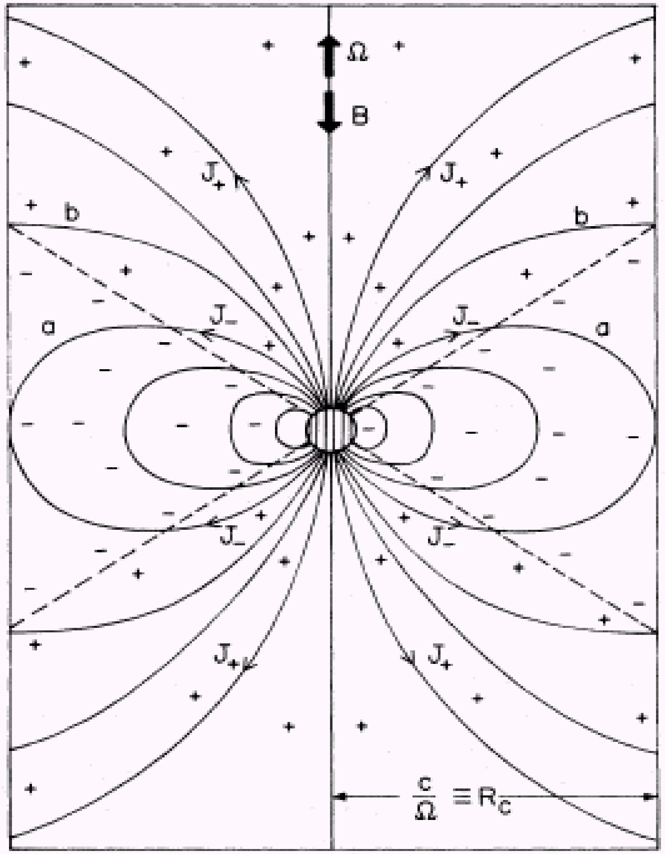
$\cos\theta = \pm 3^{-1/2}$

For Crab Pulsar:

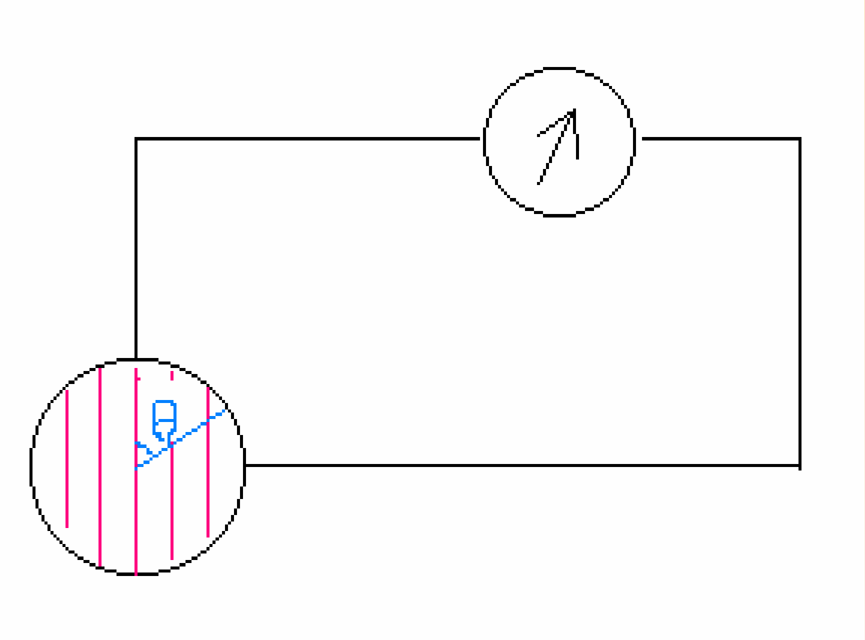
$F_e/F_g = 10^9$

$$\vec{E} + \frac{1}{c}(\vec{\Omega}\times\vec{r})\times\vec{B} = 0$$

$$\rho = \rho_+ - \rho_- = -\frac{\vec{\Omega}\cdot\vec{B}}{2\pi c}$$



单极感应电势（Mono-generator）



$$E = B_s \Omega R^2 \sin^2\theta / (2c)$$

For the Sun:

$$E_{max} = 10^7 V$$

For Crab Pulsar:

$$E_{max} = 10^{18} V$$

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加速区可能的部位

$$\rho \neq \rho_{gj}$$

1. Gap: *inner gap* & *outer gap*
2. Space Charge Limited Flow:
   Slot gap
3. *Annular gap*

加速区形成的条件

在光速圆柱附近损失粒子➔

I. 真空Gap

1). Inner gap: 中子星表面束缚能大(14KeV)

2). outer gap: 磁层中电荷完全分离

3). Annular gap:

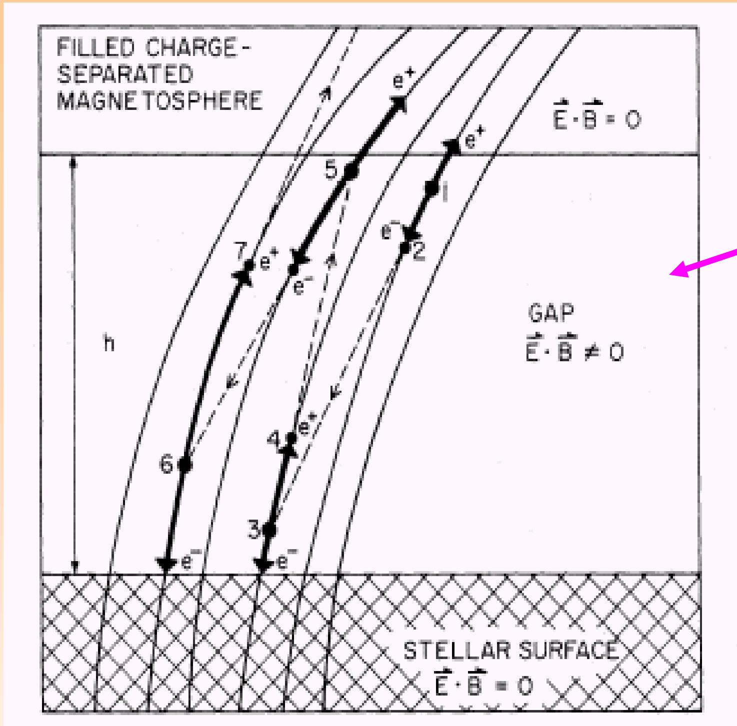
真空 gap—夸克星，或者平行转子

磁层中有中性成分

II. Free flow:

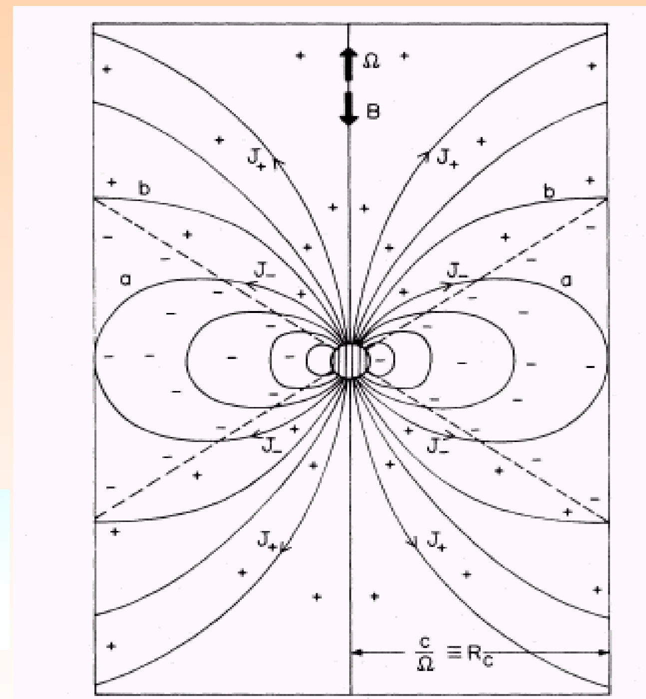
slot gap & Annular gap

Inner gap



GAP

$\vec{E}\cdot\vec{B}\neq 0$



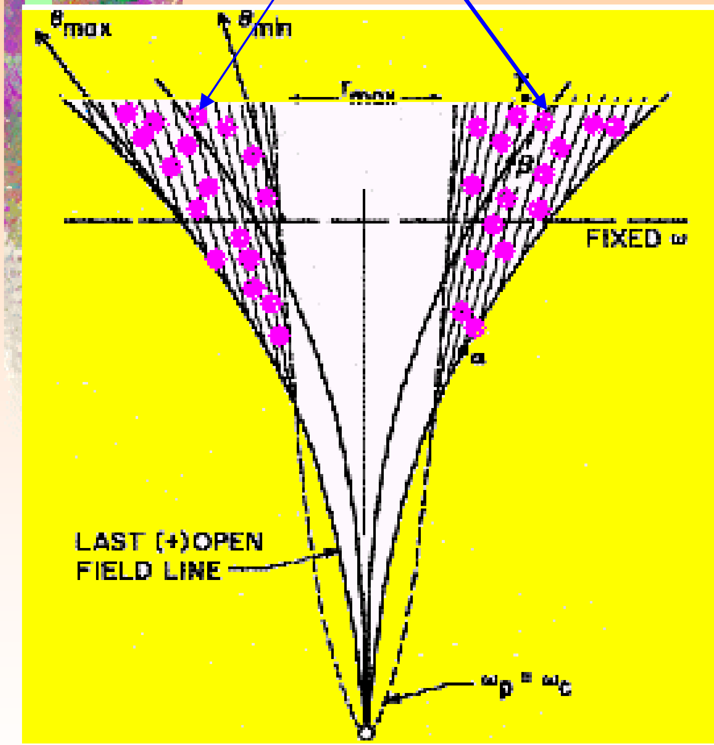
1、磁轴与自转轴“反平行”

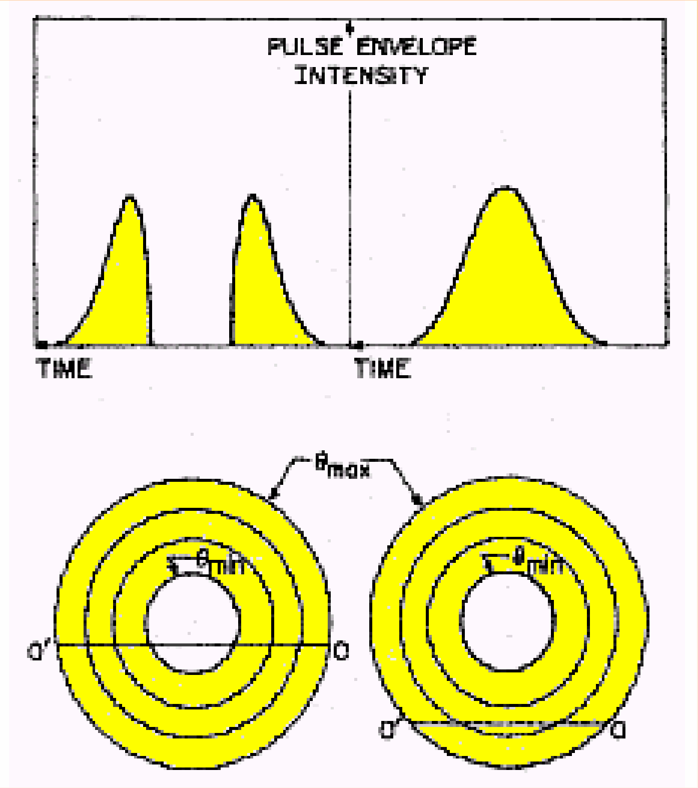
2、中子星表面有强大束缚能

Ruderman & Sutherland ,1975,ApJ

Emission beams in RS model

Emission beams





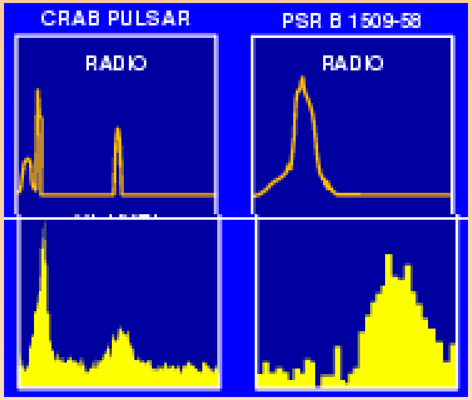
Hollow cone only!
Low freq: wide beam!

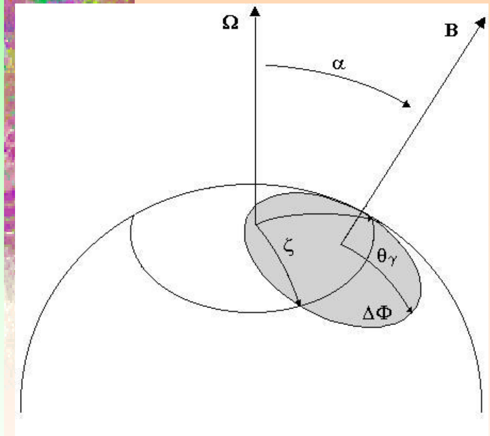
Ruderman & Sutherland, 1975

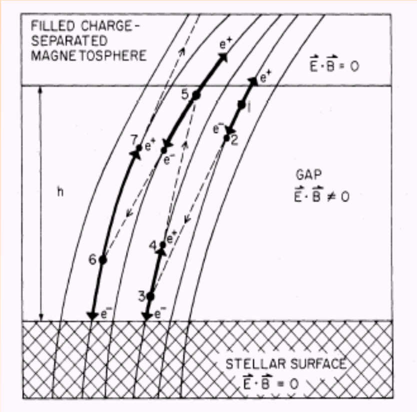
Polar gap & Outer gap

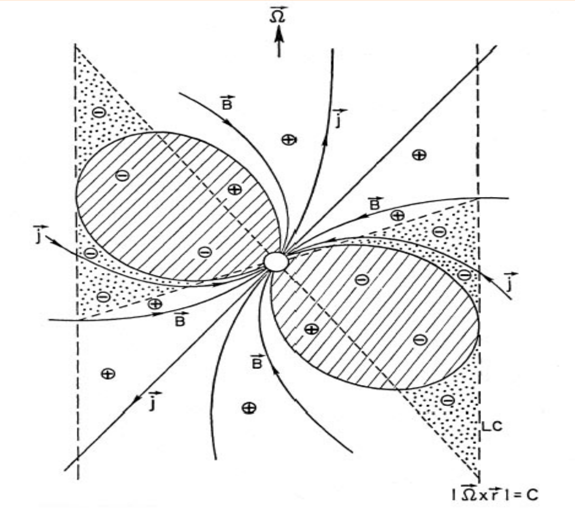
☆**Radio--- Gamma-rays:**

Obs.









Polar cap (gap)

(Harding, 1981; RS, 1975)

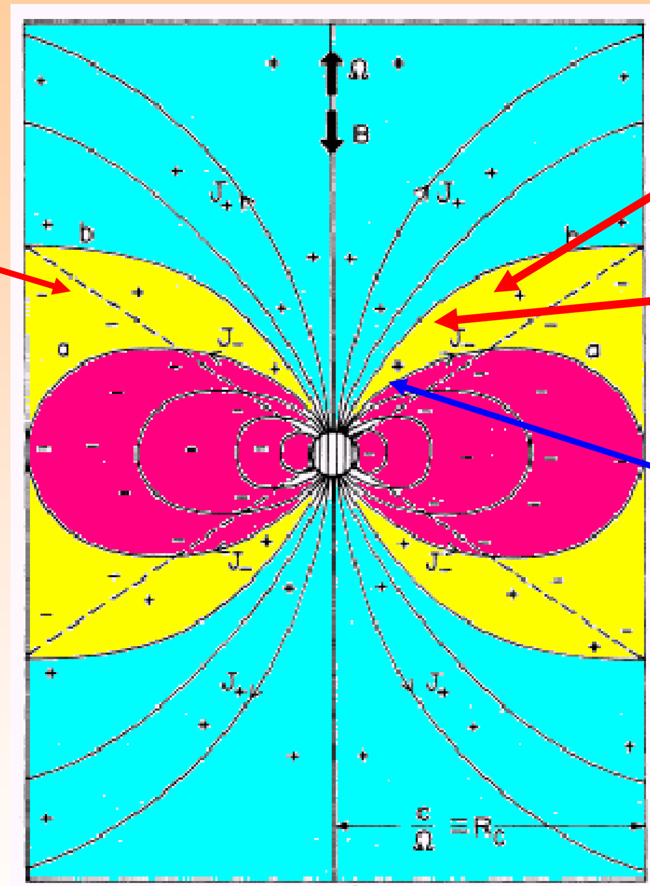
Outer gap

(Cheng et al. 1986)

Two polar cap regions

The annular gap

$\cos\theta = \pm 3^{-1/2}$



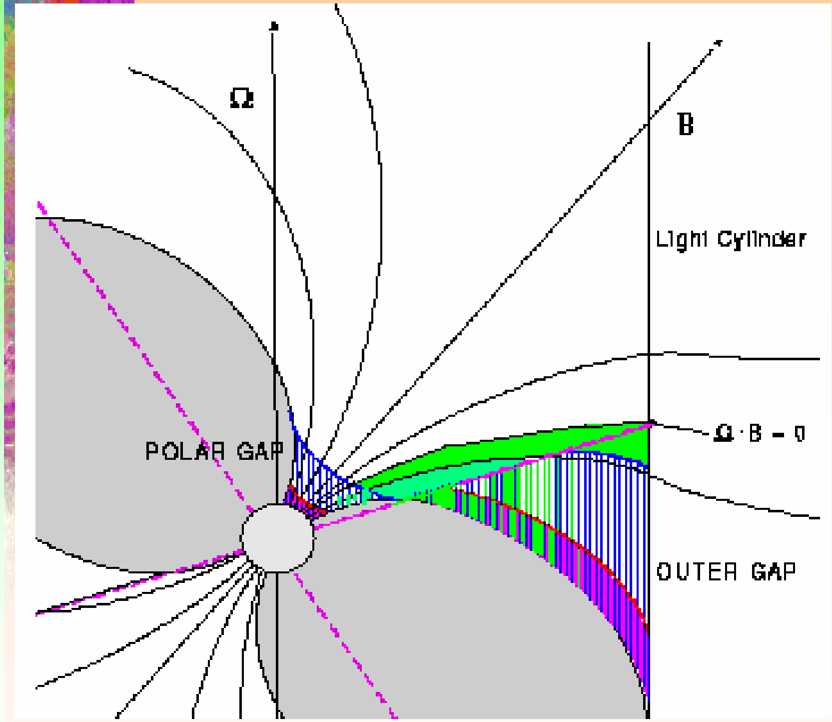
$r_{\text{in}} = 0.74\Omega^{0.5}R^{1.5}c^{0.5}$

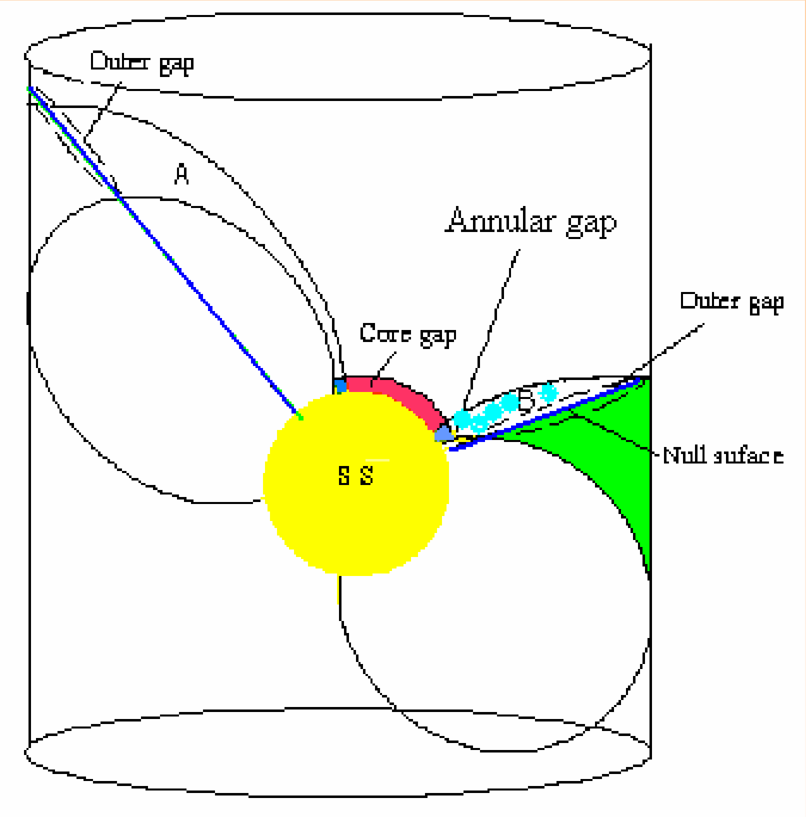
$r_p = \Omega^{0.5}R^{1.5}c^{0.5}$

$$\boldsymbol{E} + \frac{(\boldsymbol{\Omega} \times \boldsymbol{r})}{c} \times \boldsymbol{B} = 0$$

$$\rho_e = -\boldsymbol{\Omega}\cdot\boldsymbol{B}(2\pi c)^{-1}$$

The annular gap





free flow

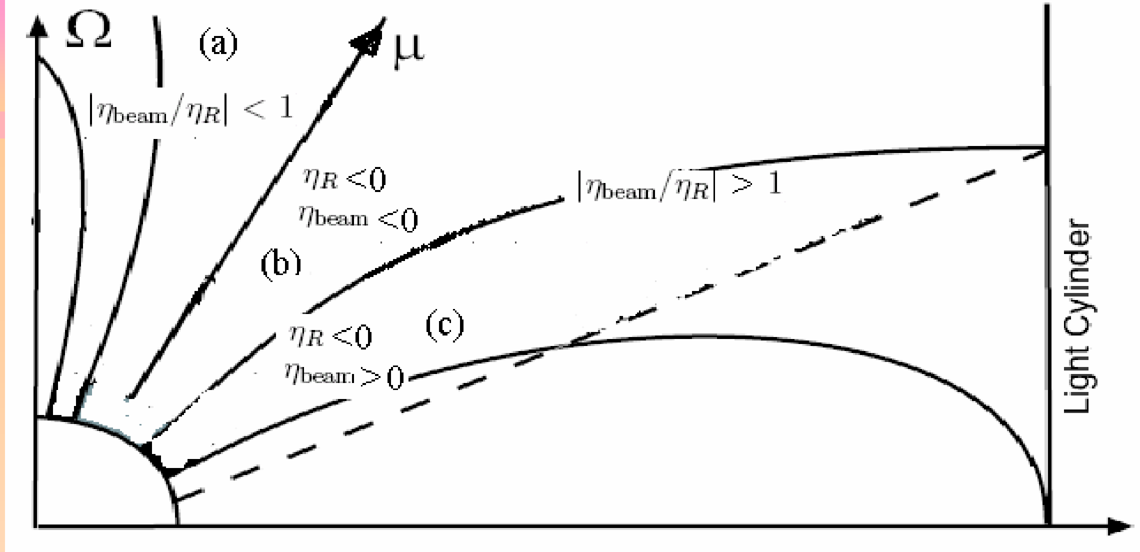
The boundary conditions are the same as that the authors used before.

(1) $E_{||} = 0$ at the surface level

(2) $\Phi = 0$ at the surface and at the interface between the closed magnetosphere and the open field lines

(3) Fully charge separated magnetosphere.

$$\nabla \cdot \boldsymbol{E} = 4\pi(\rho - \rho_{gj})$$



--Region (a), a "favorable" region, which means that the electric field towards to the star surface, and the negative electric particles can be accelerated.

--Region (b), owing to $|\eta_{beam}/\eta_R| > 1$, $\eta_R < 0$ and $\eta_{beam} < 0$, the negative electric particles can not accelerated easilly.

--Region (c), they did not consider this region.

The polar cap model

above the polar cap are (Muslimov & Tsygan1992):

1) $E \cdot B = 0$ for the magnetosphere within the closed field lines,

2) $\Phi = 0$ at the surface and at the interface between the closed magnetosphere and the open field lines,

3) $E_{||} = 0$ at the surface level, where $E_{||}$ is the electric field component parallel to the magnetic field.

4) Last but not least, it is assumed that the **outflow is stationary** and the magnetosphere **remains axisymmetric**.

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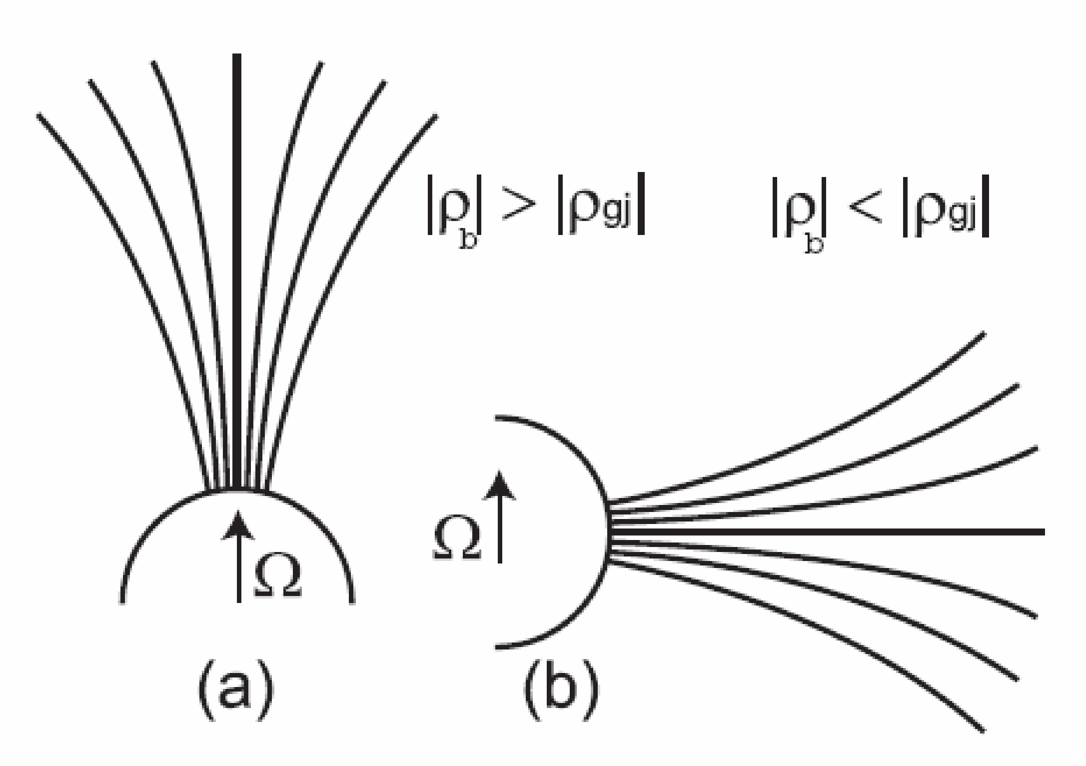
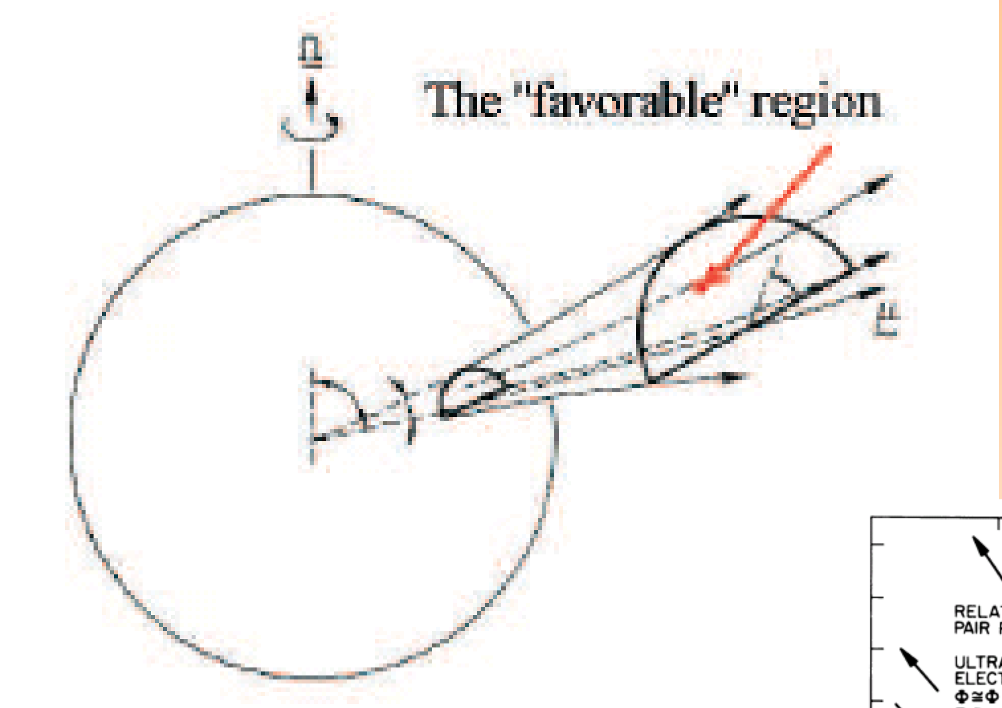
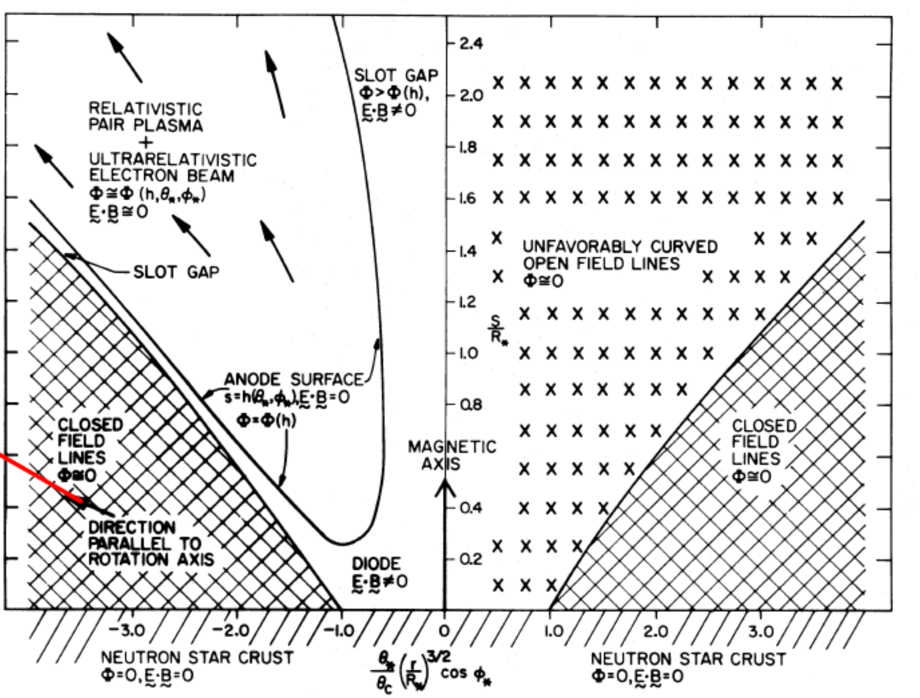
5、伽玛射线辐射与射电如何统一研究?



在中子星表面 $\rho = \rho_{gj}$

Arons and Scharlemann(1979)

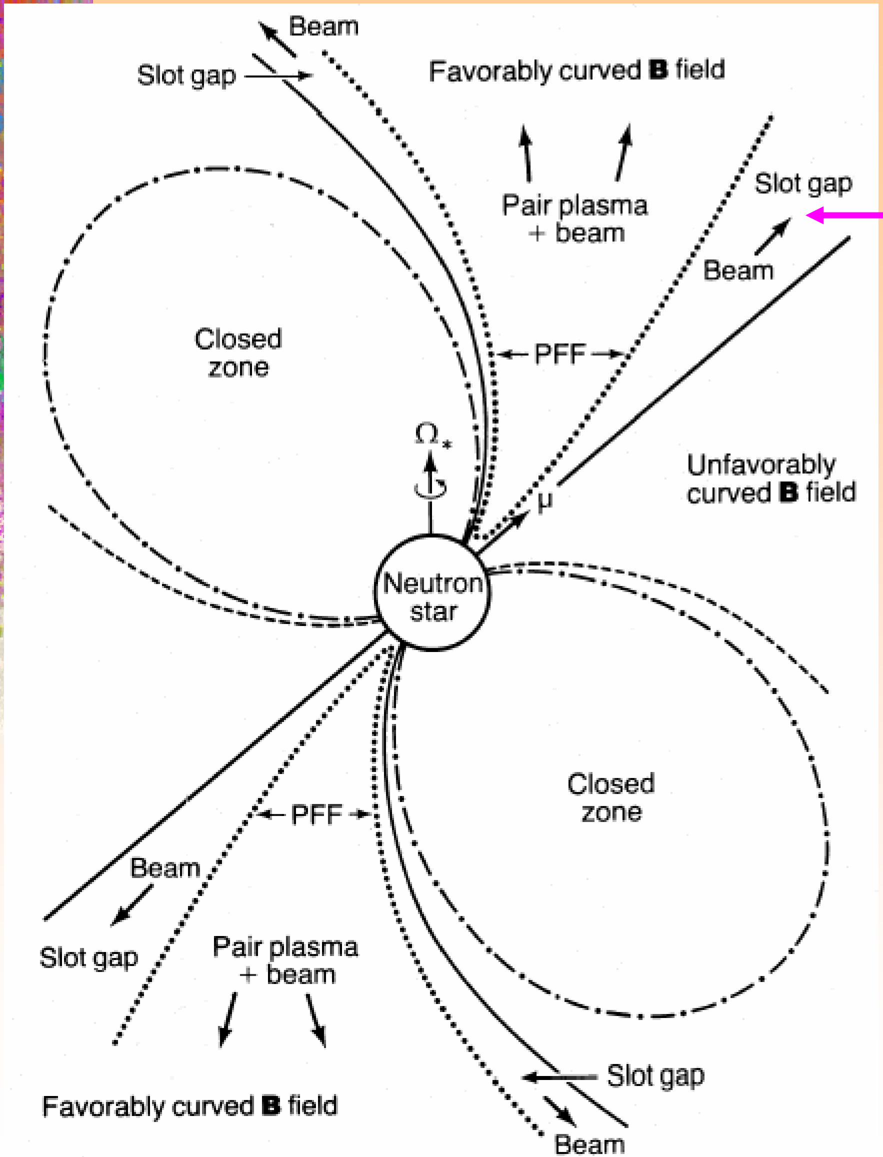




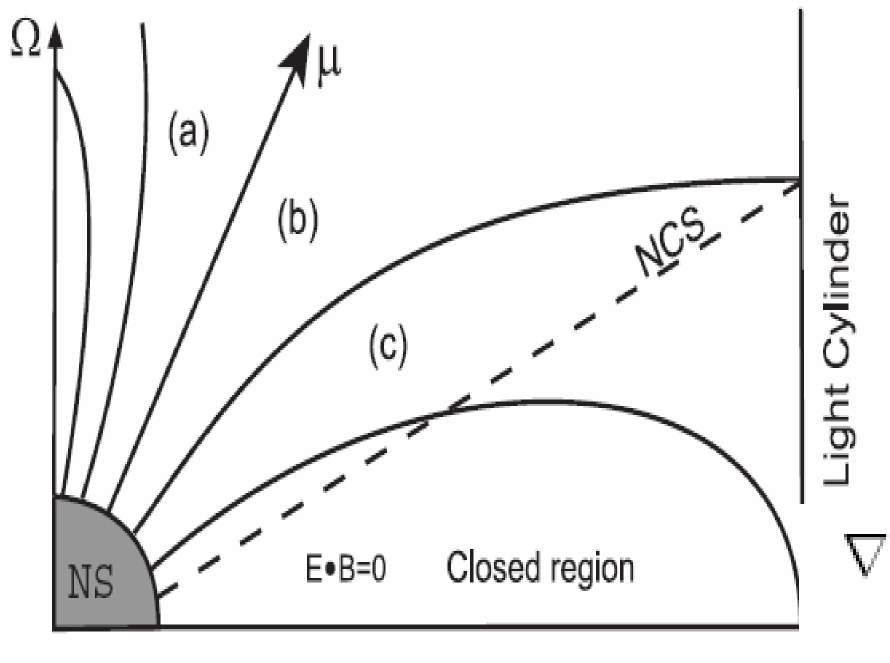
在中子星表面

$$\rho = \rho_{gj}$$

Slot gap model



Arons,J. 1983, ApJ



$$\nabla \cdot E = 4\pi(\rho_b - \rho_{gj}),$$

$$\rho_{\rm gj}(r) = -\frac{\mathbf{\Omega}\cdot\mathbf{B}(\mathbf{r})}{2\pi c}\left[1 - k_{\rm g}\left(\frac{R}{r}\right)^3\right],$$

$$\rho_b(r) = -\frac{\mathbf{\Omega}\cdot\mathbf{B}(\mathbf{R})}{2\pi c}(1-k_g)\frac{|\mathbf{B}(\mathbf{r})|}{|\mathbf{B}(\mathbf{R})|}.$$

$$\rho_b(r) - \rho_{gj}(r) = -\frac{\Omega B(r)}{2\pi}(\cos\zeta_1 - \cos\zeta),$$

$$\rho_{\rm b}(r)/\rho_{\rm gj}(r) = \frac{\cos\zeta(R)}{\cos\zeta(r)}.$$

Qiao, Cui , Lee, Wang , Xu 2006

加速区、辐射区有关的讨论

1、粒子流的因果关系

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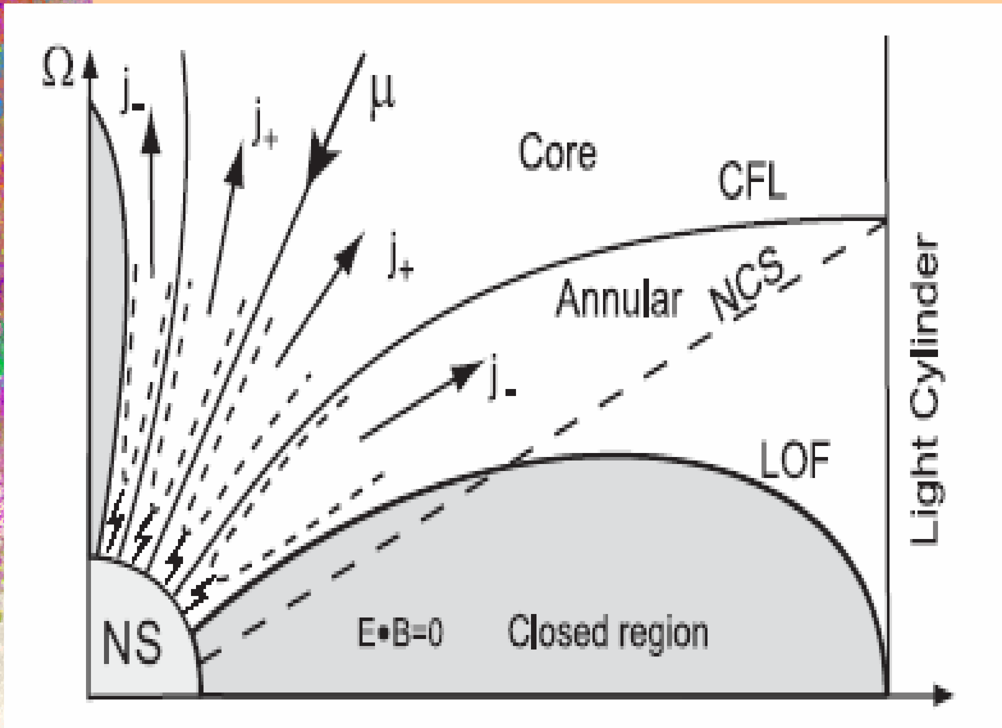
（加速区不等于辐射区；是否同时有2个或者2个以上的加速区、辐射区）

5、伽玛射线辐射与射电如何统一研究?

The annular gap



$$\nabla \cdot E = 4\pi(\rho_b - \rho_{gj}),$$

$$\nabla^2 \Phi = -4\pi(\rho_b - \rho_{gj}),$$

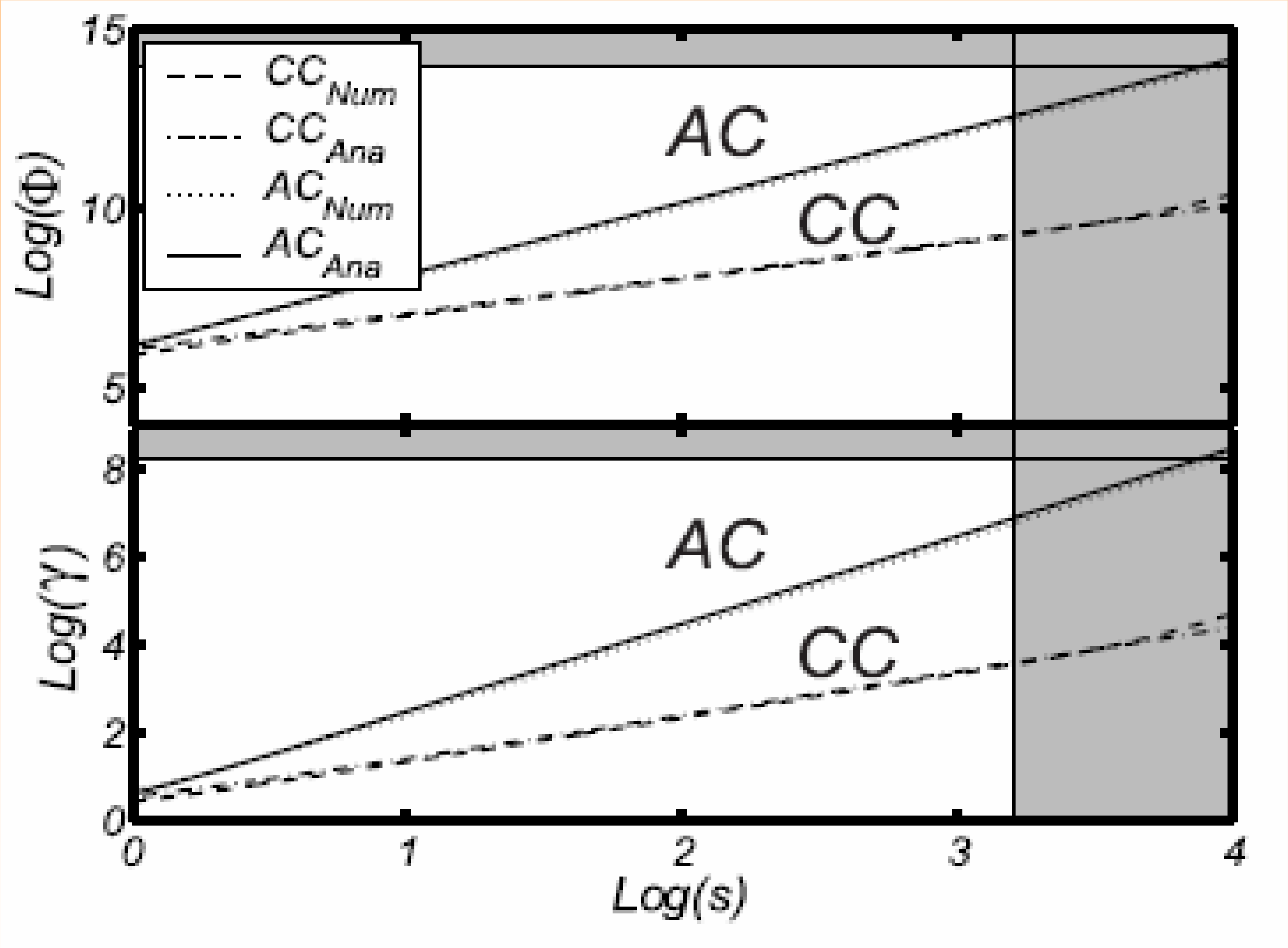
$$\rho_{gj} = -\frac{\Omega \cdot B(r)}{2\pi c}[1 - k_g(\frac{R}{r})^3],$$

$$\rho_b = -\frac{\Omega \cdot B_0}{2\pi c}(1 - k_g)(\frac{B(r)}{B_0})$$

$$\rho_b/\rho_{gj} = \frac{\cos\zeta_0}{\cos\zeta}.$$

Qiao,Lee,Zhang,Wang,Xu, 2007,ChJAA

The annular gap



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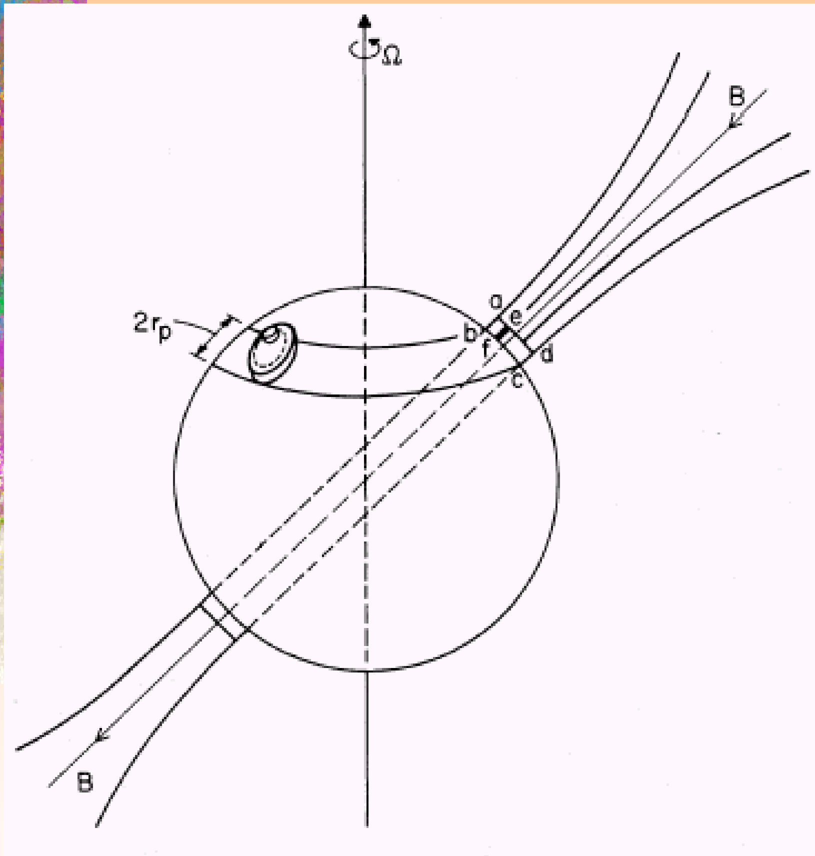
Drifting sub-pulses



Accelerators:

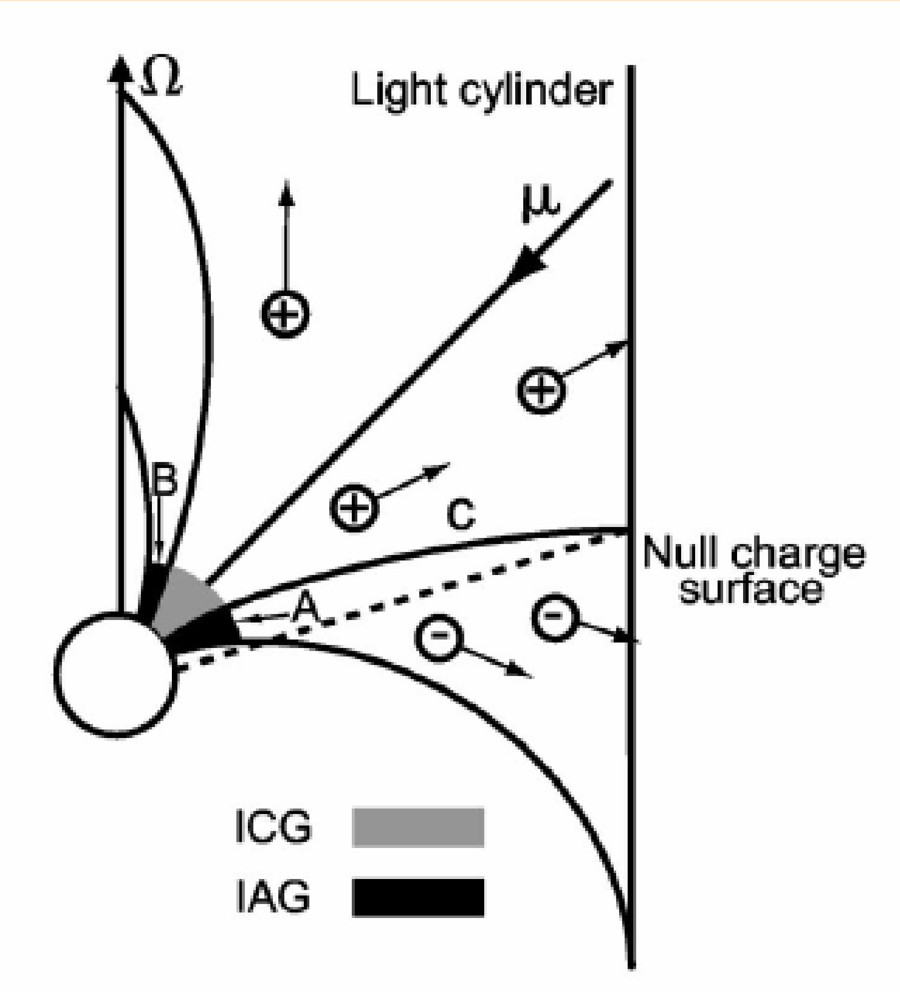
- Inner vacuum gap (Ruderman & Sutherland 1975)

requiring high binding energy of charges on stellar surface

Xu,Qiao Zhang, 1999,ApJL,522,L112

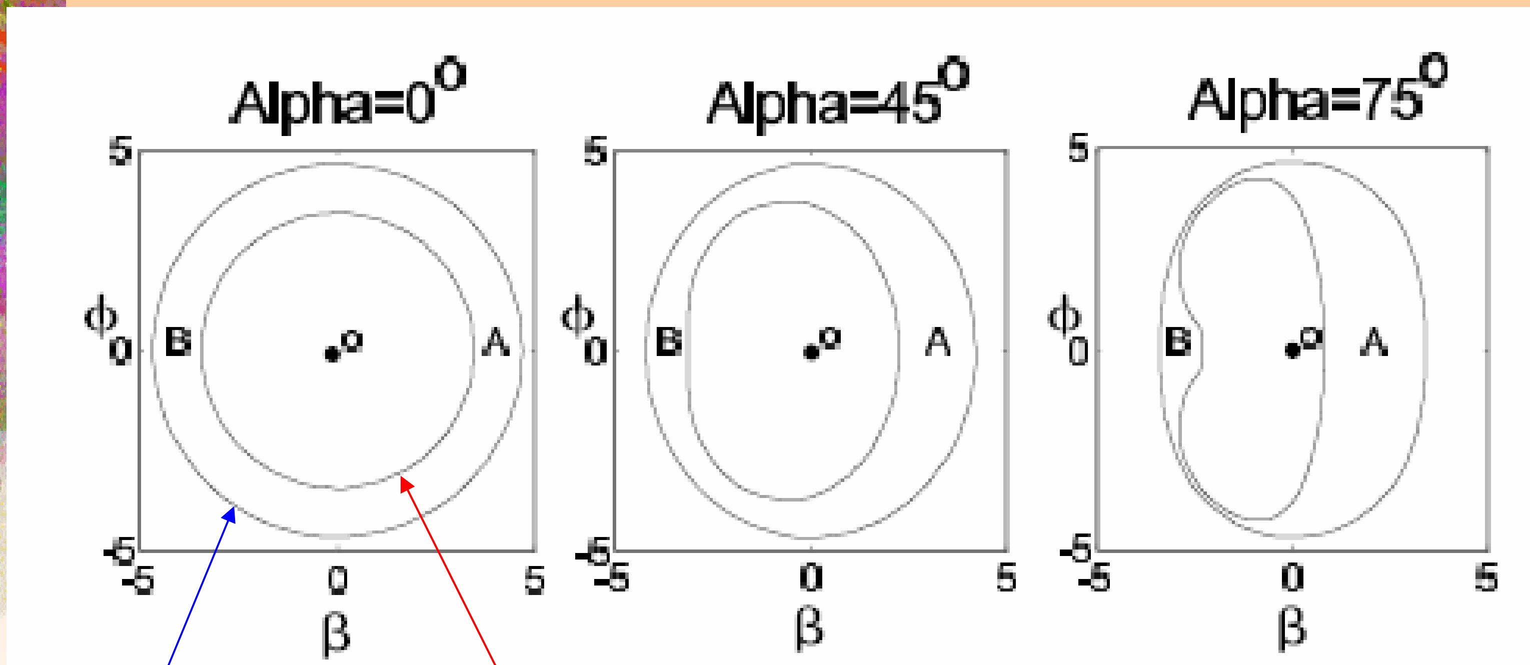
Deshpannde & Rankin, 1999,ApJ, 524,1008

Inner annular gap



Qiao,Lee,Wang,Xu,Han 2004a, ApJL

Inner annular gap

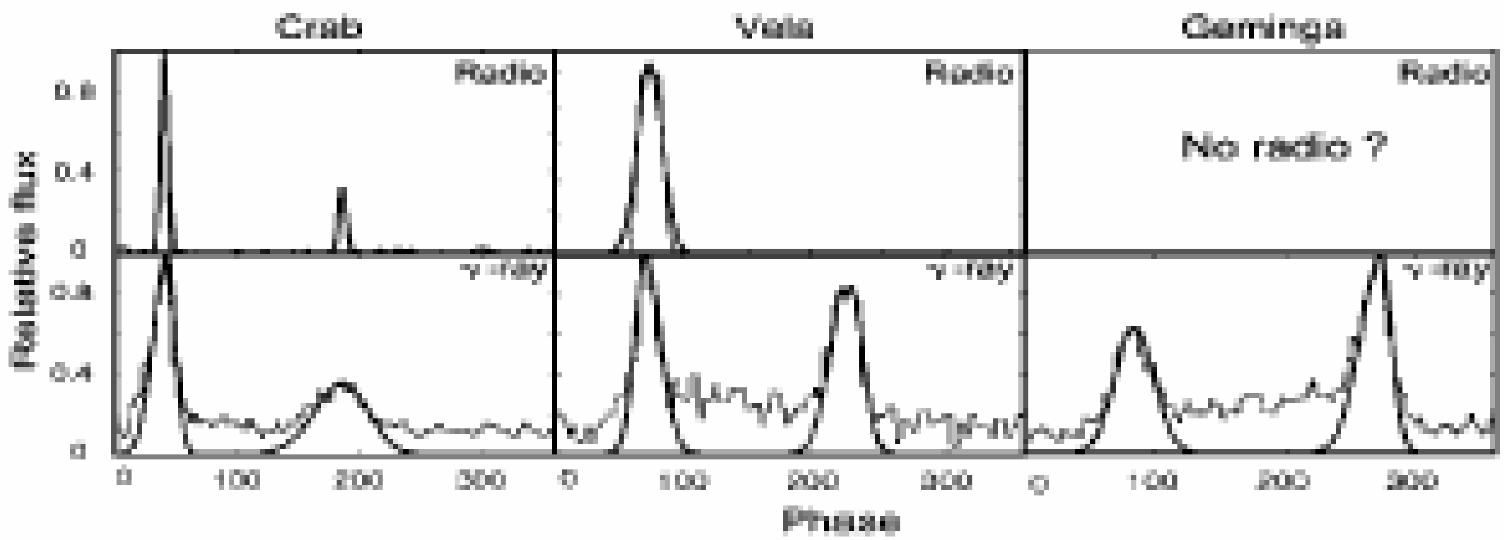


$r_p = \Omega^{0.5} R^{1.5} c^{0.5}$

$r_{\rm in} = 0.74 \Omega^{0.5} R^{1.5} c^{0.5}$

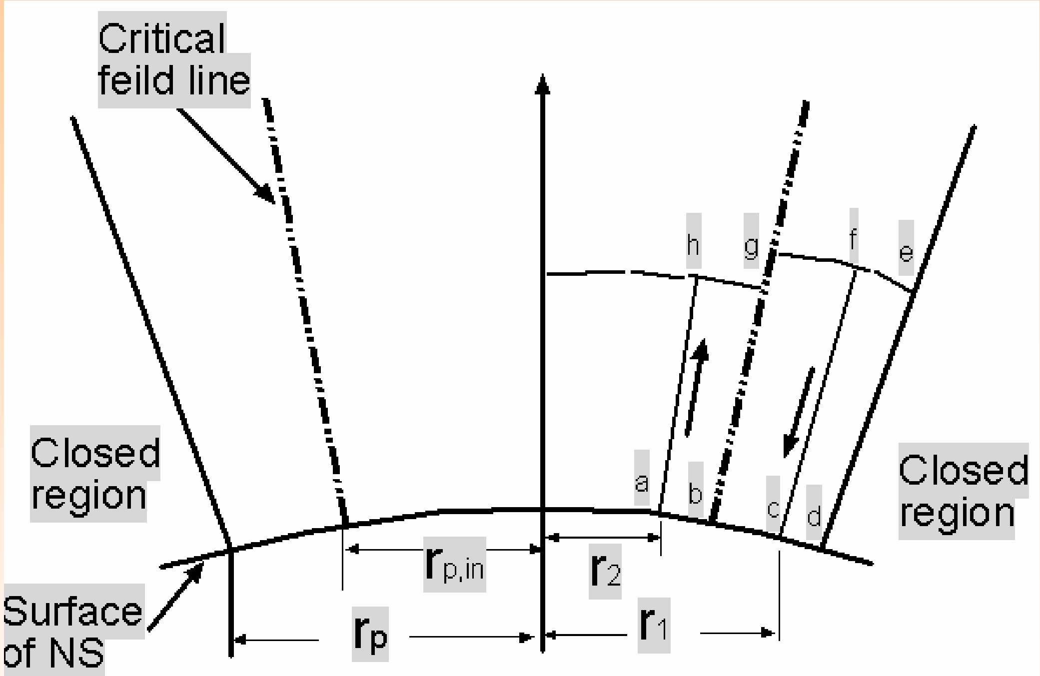
Qiao,Lee,Wang,Xu, Han, 2004a,ApJL

Inner Annular Gap



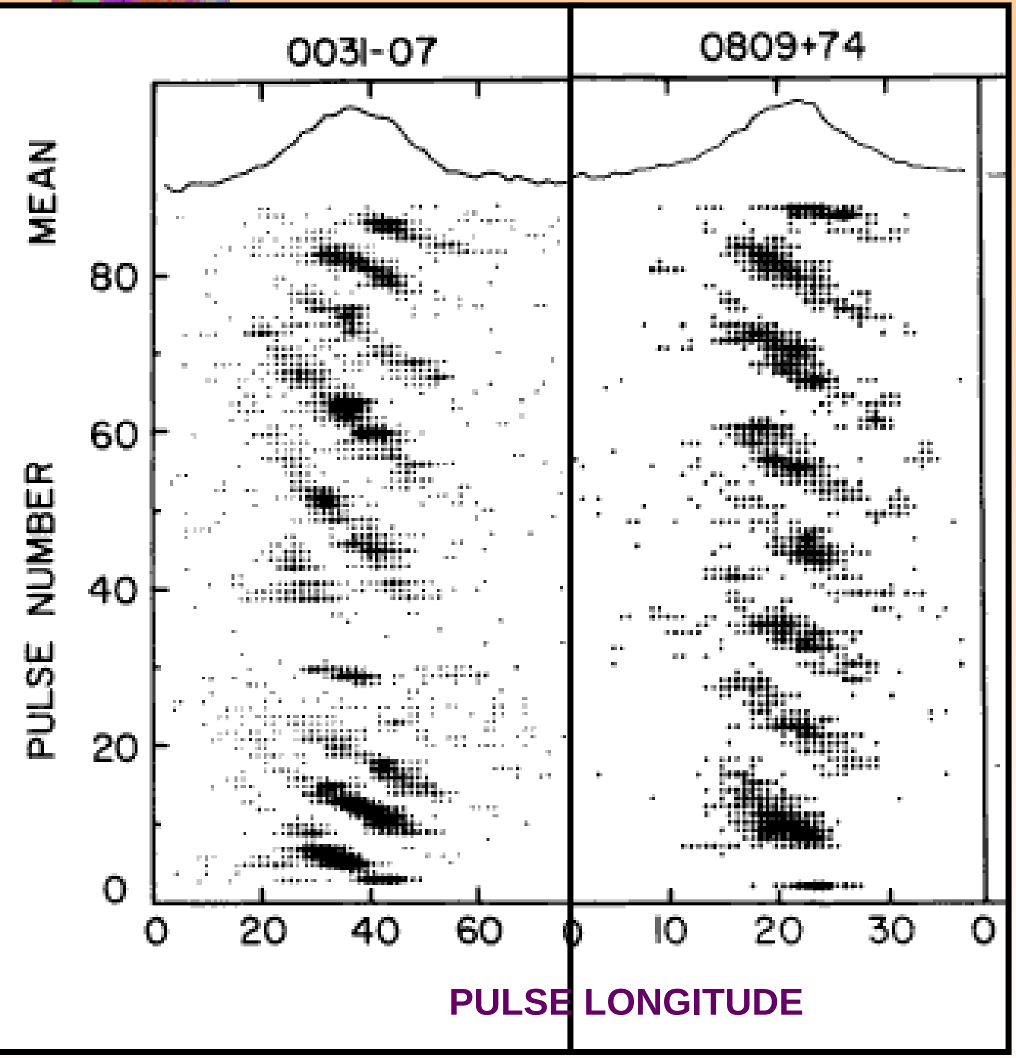
Qiao,Lee,Wang,Xu, 2004a, ApJL

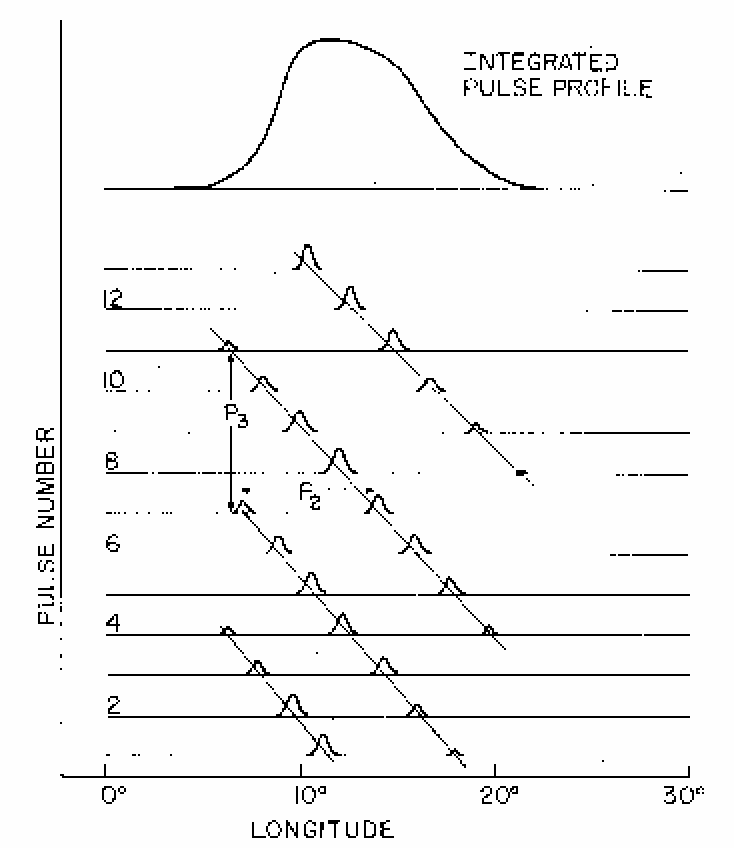
Inner Annular Gap : V= c E x B / B^2



$$\mathbf{v} = \mathbf{E} \times \mathbf{B} / |\mathbf{B}|^2$$

Drifting subpulses





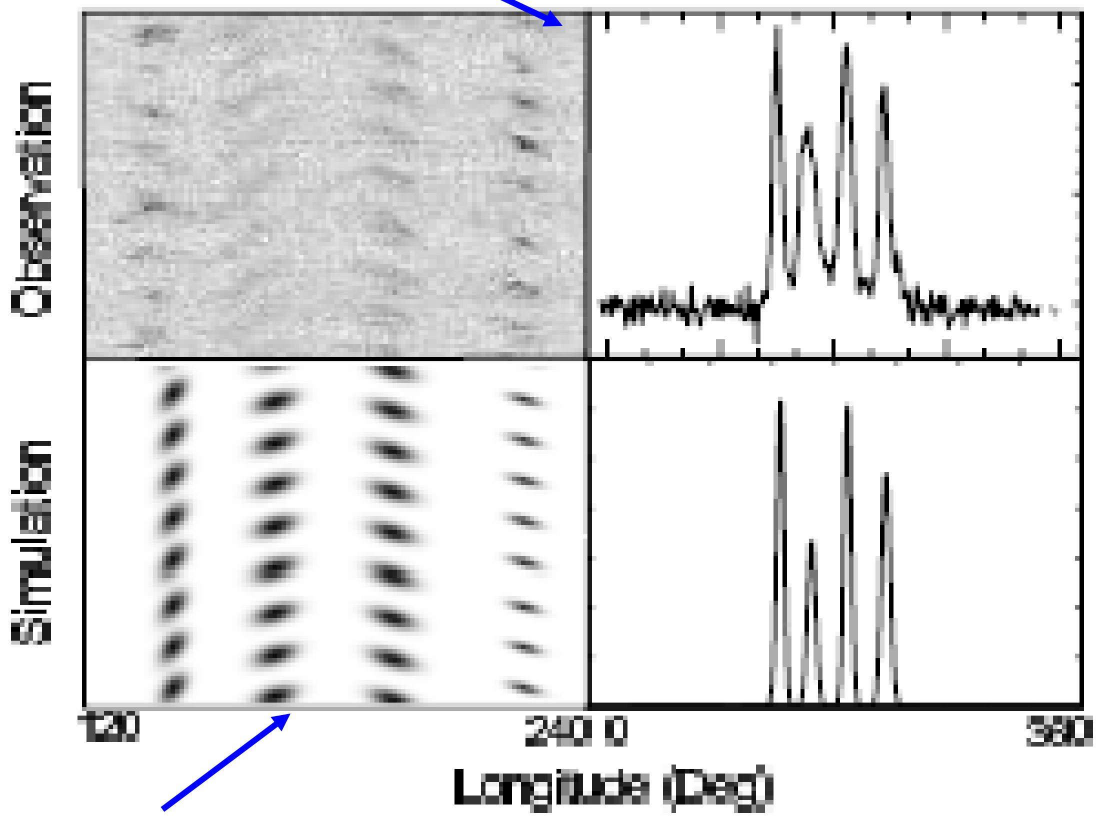
Drifting subpulses

Taylor et al. (1975)

Backer (1973)

Bi-drifting: fitting

Mclaughlin 2003,astr-ph/0310454



Qiao,Lee,Zhang,Xu,Wang,2004b, ApJL

加速区、辐射区有关的讨论

1、粒子流的因果关系

2、磁层是否完全电荷分离？

3、是否有真空内gap？夸克星？

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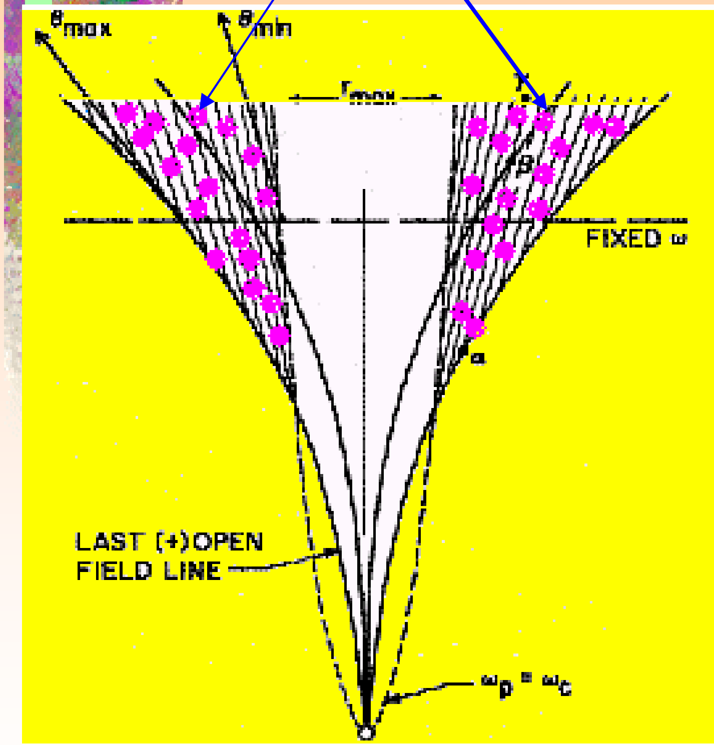
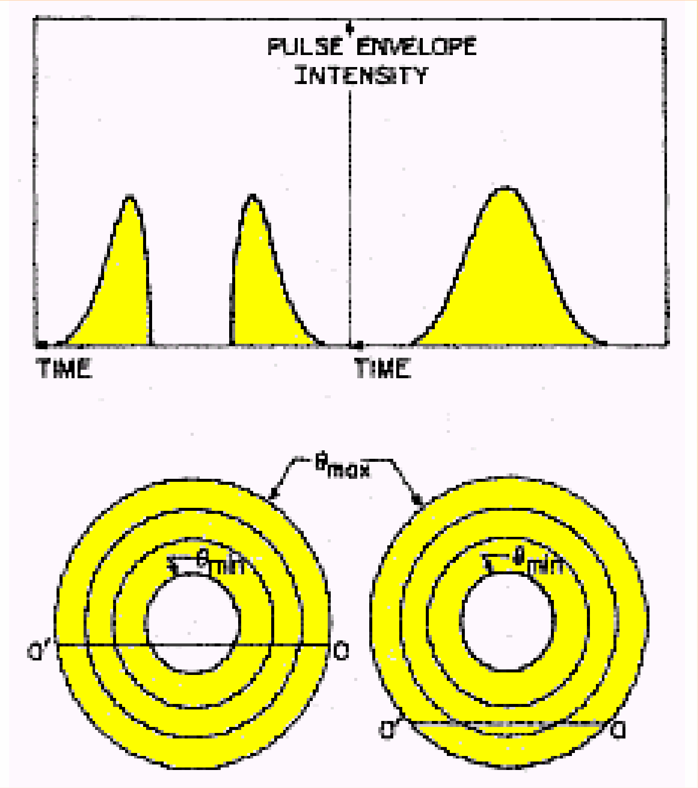
（加速区不等于辐射区；是否同时有2个或者2个以上的加速区、辐射区）

5、伽玛射线辐射与射电如何统一研究？

Emission beams in RS model

Emission beams



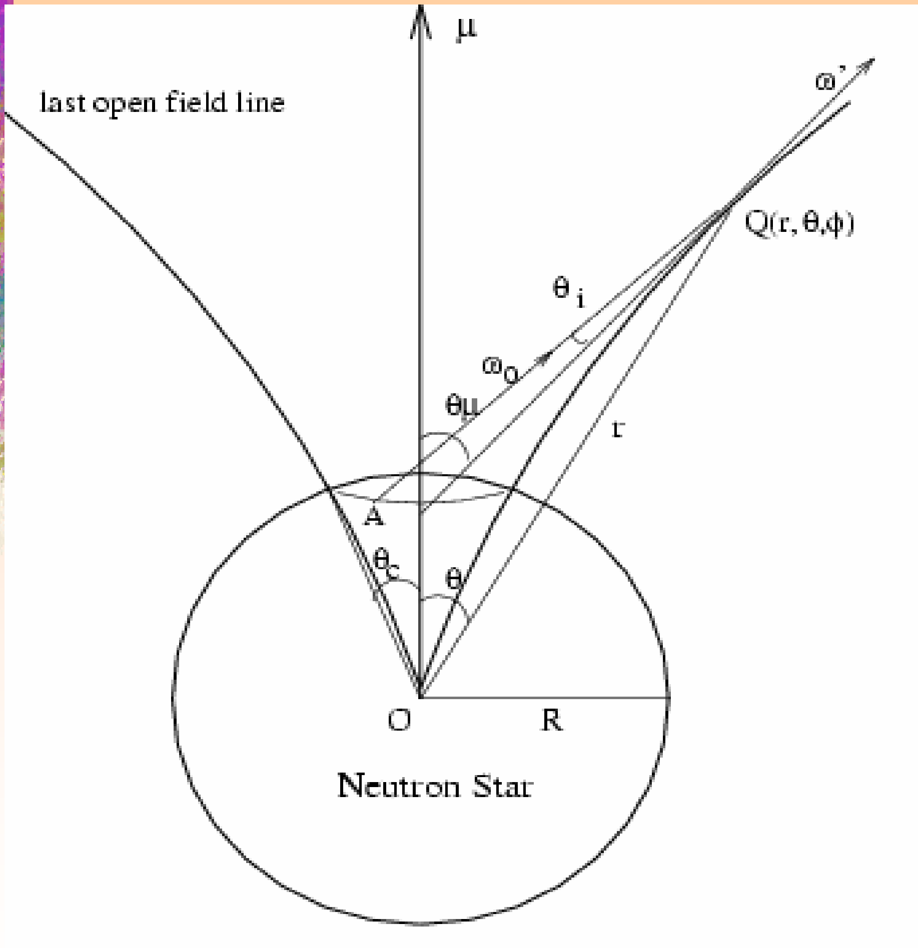


Hollow cone only!
Low freq: wide beam!

Ruderman & Sutherland, 1975

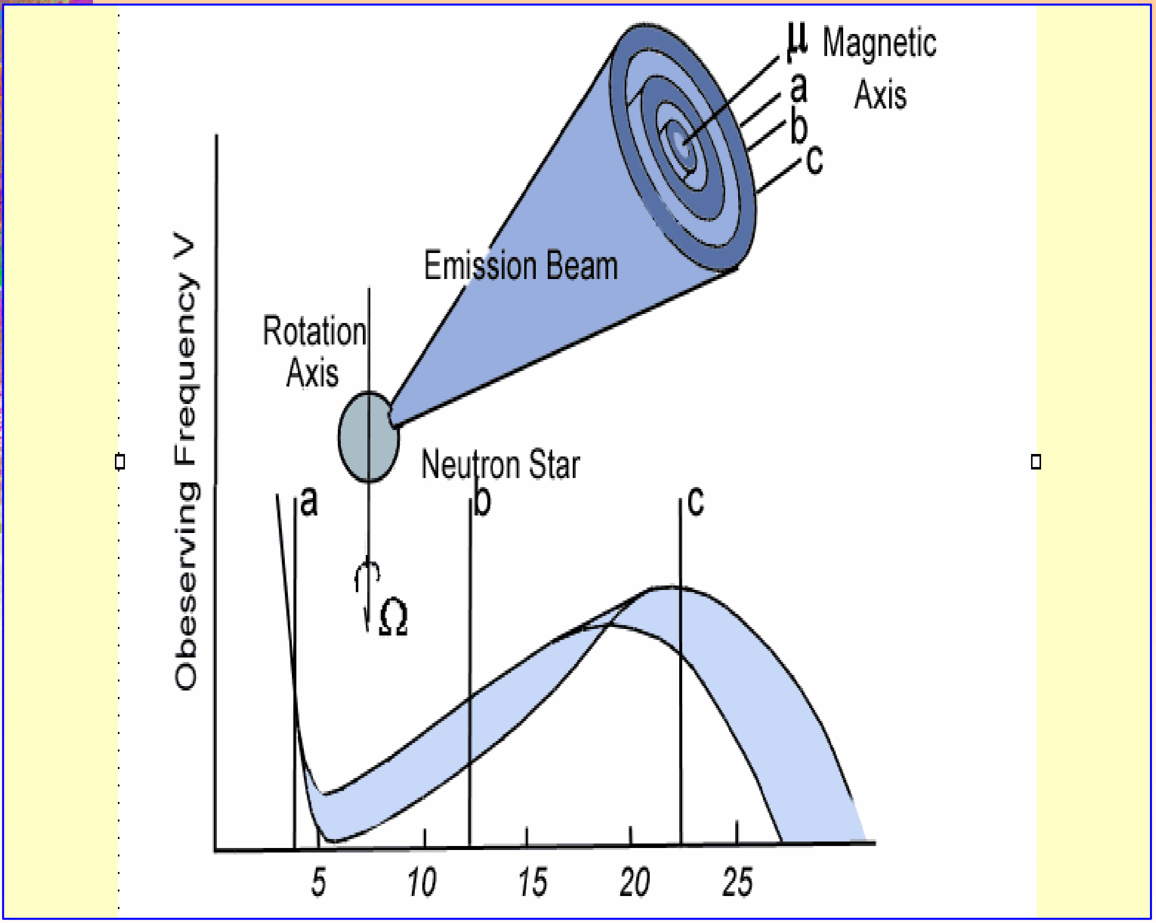
Basic picture of the ICS model

Qiao & Lin,1998, A&A

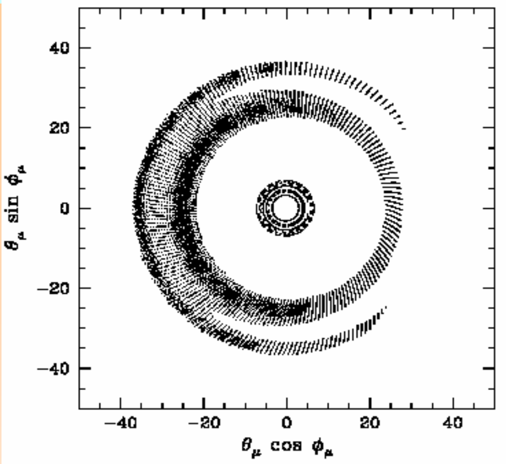


$$\omega = 2\gamma^2 \omega_0 (1 - \beta \, \mathrm{Cos}\, \theta_i)$$

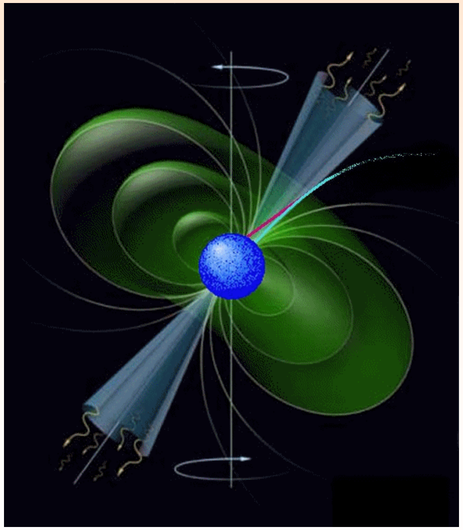
ICS Model: emission beams   Core +cones

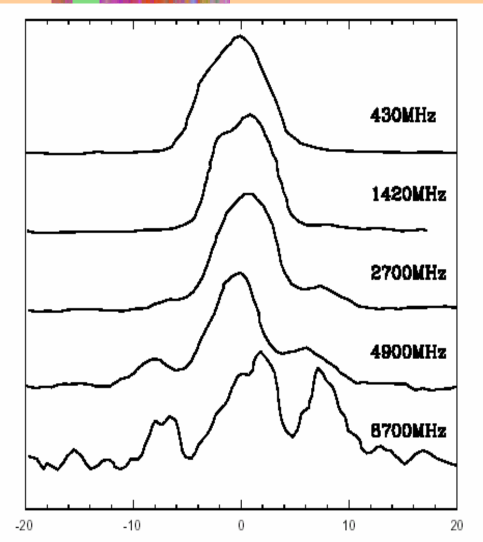


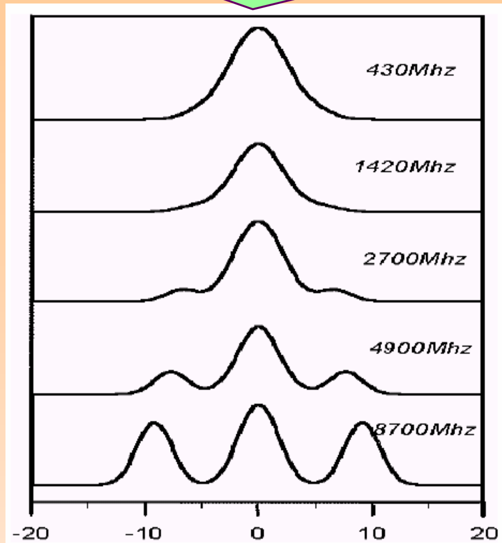
Qiao, 1992

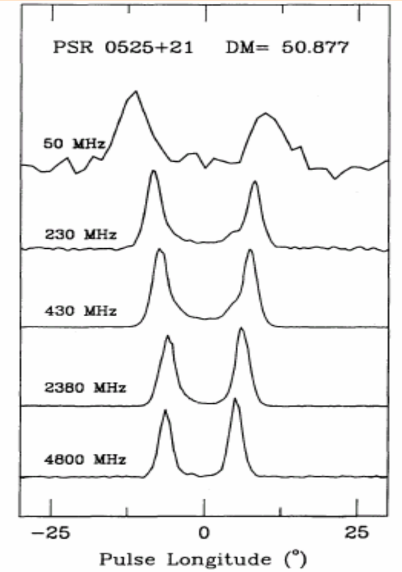


Qiao & Lin, A&A,1998

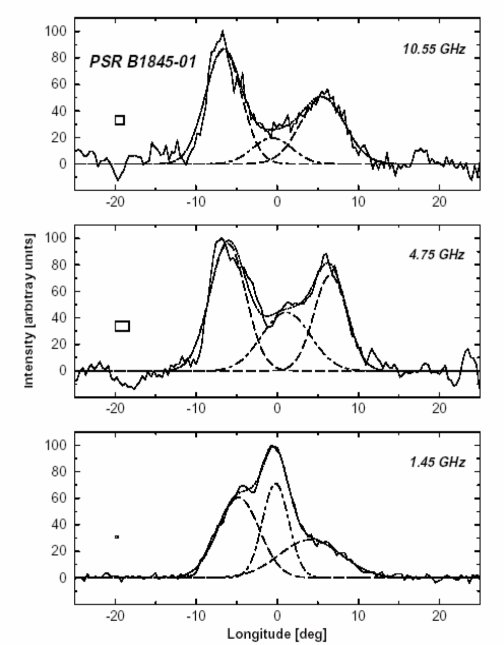


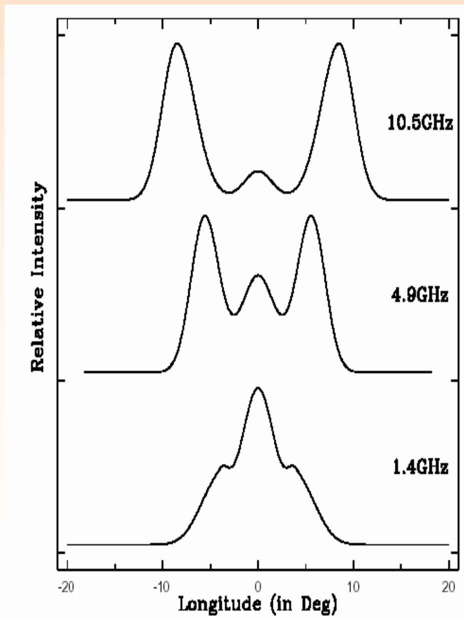






RS model



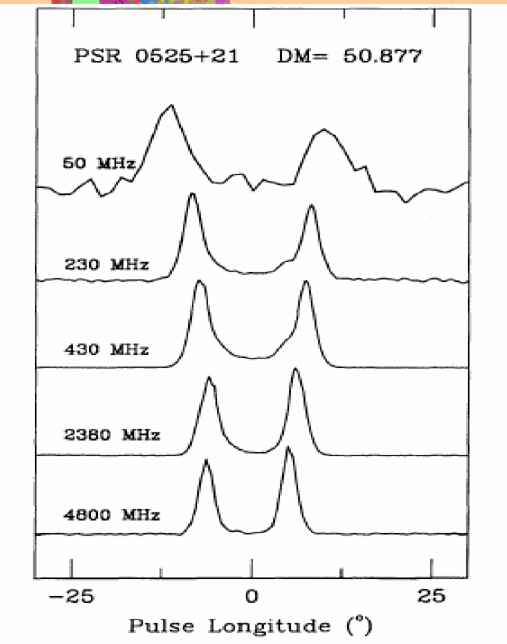


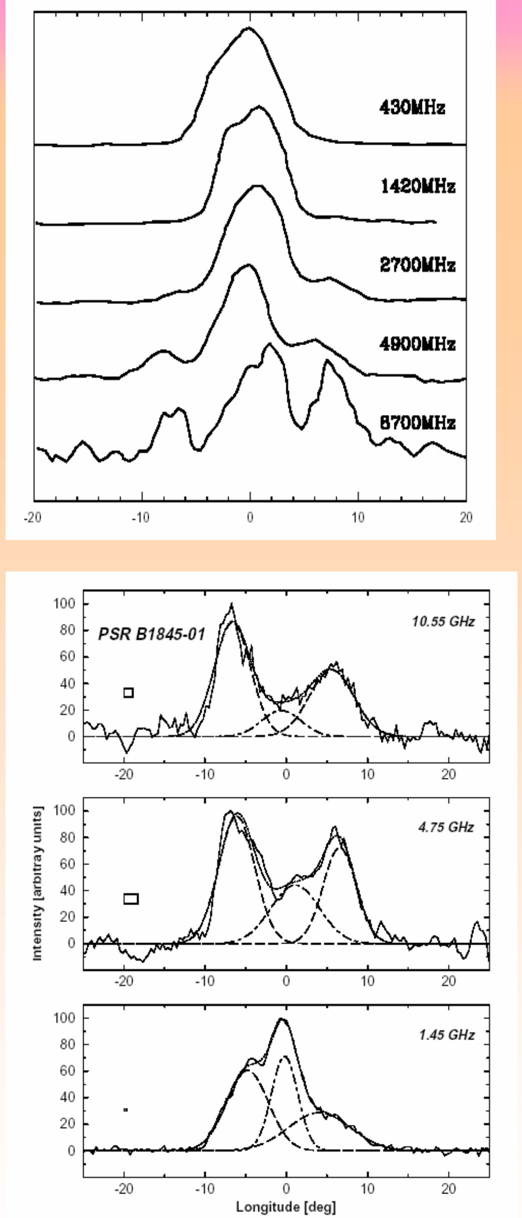
There are various beam width- frequency relations, which can not be simple explained by RS model.

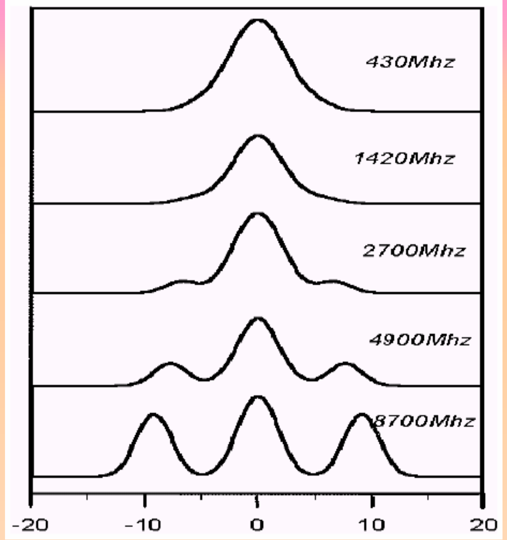
Qiao,Liu, Zhang,& Han, 2001,AA

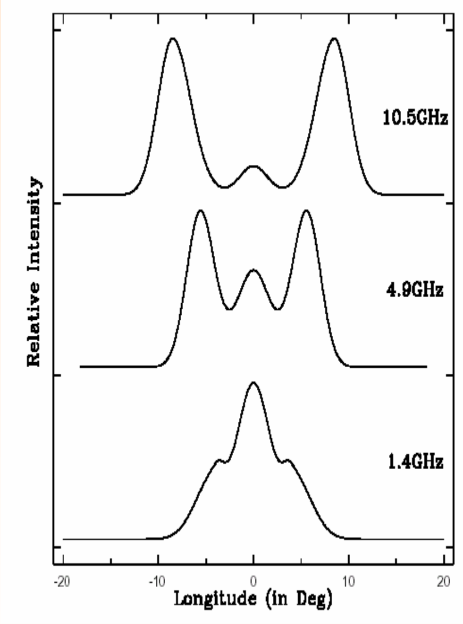
Lyne & Manchester (1988) & Sieber et al. (1975),Kramer,(1994)

RS model



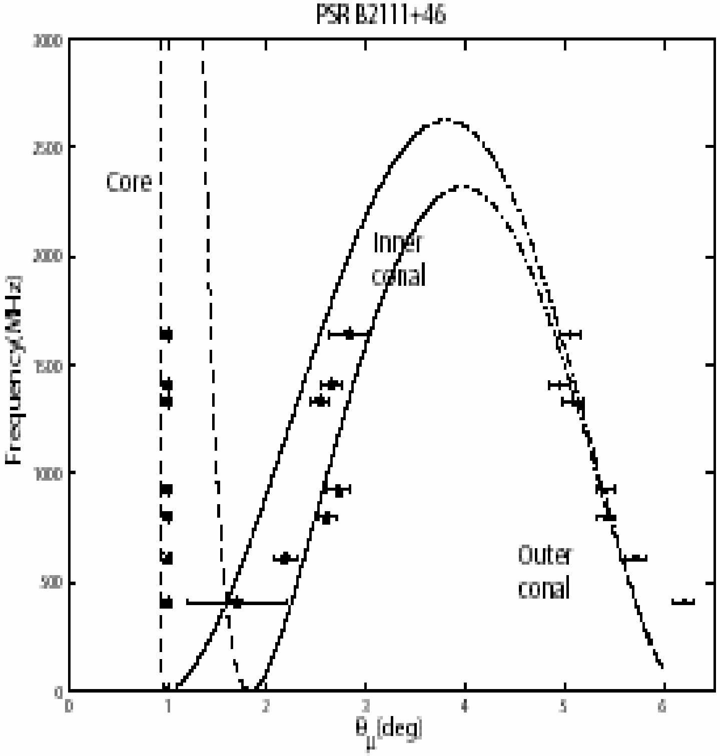


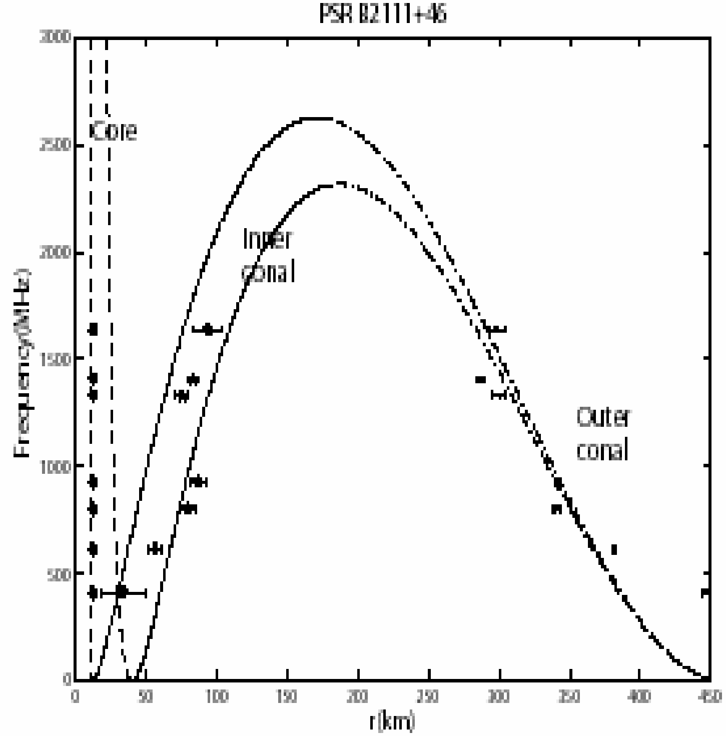


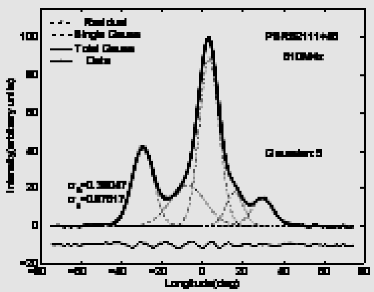


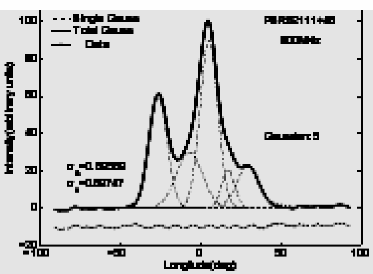
Lyne & Manchester (1988) & Sieber et al. (1975),Kramer,(1994)

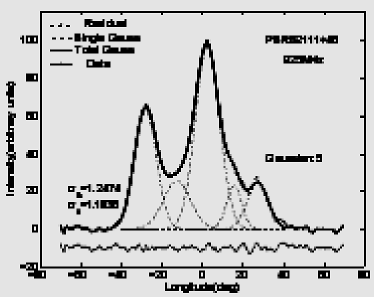
Qiao,Liu, Zhang,& Han, 2001,AA

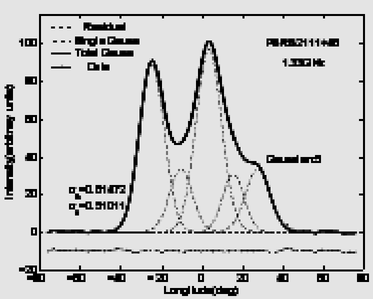


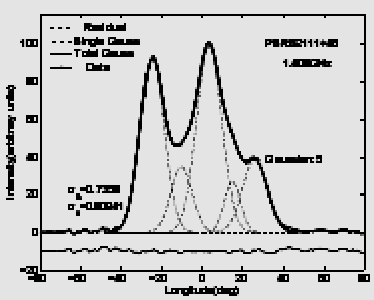












Different components of same frequency come from different altitudes.

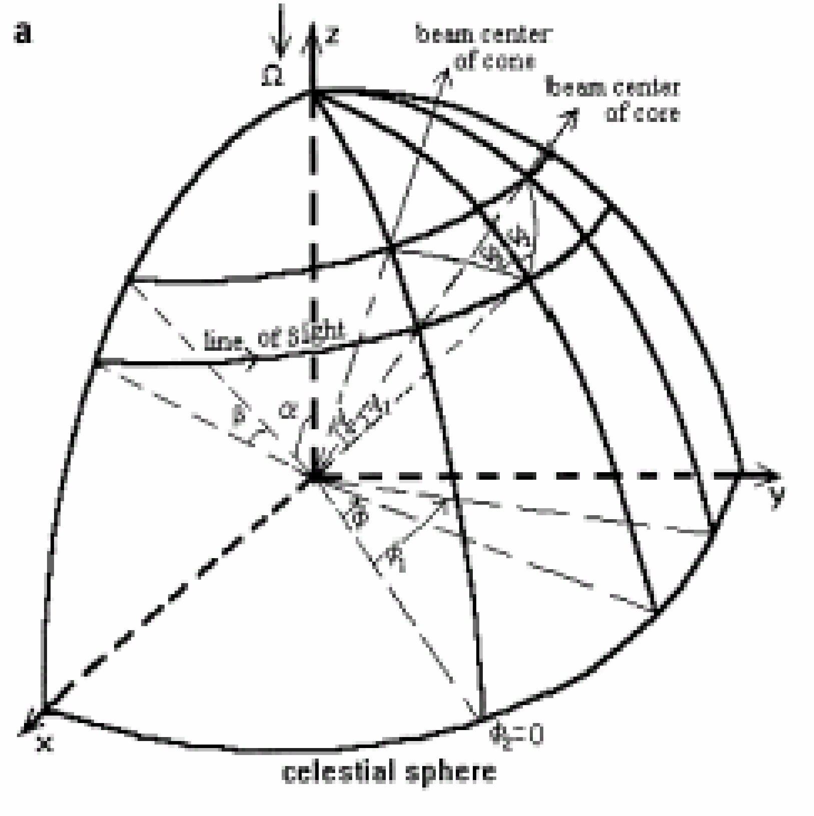
Zhang, Qiao, Han, Lee, Wang , AA,2007

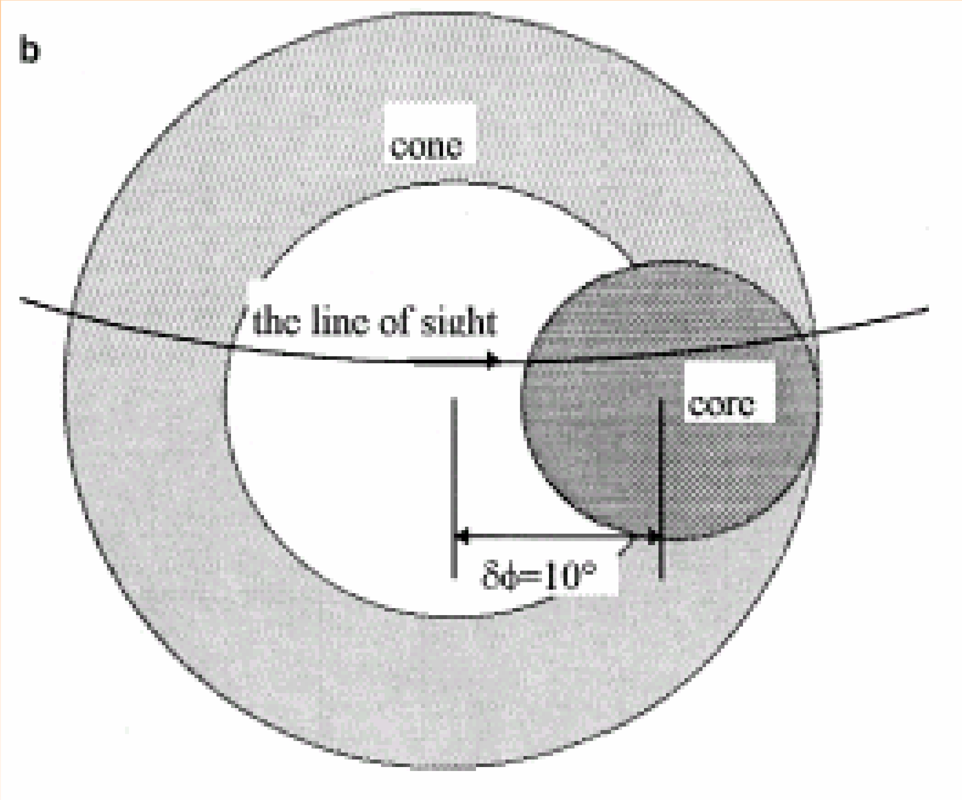
辐射区的高度

Frequency	$\Delta\phi(^\circ)$	$\alpha = 9^\circ, \beta = 1.4^\circ$ $\theta_\mu(^\circ)$	$r(\mathrm{km})^a$	$r(\mathrm{km})^b$	$\alpha = 11.6^\circ, \beta = -1^\circ$ $\theta_\mu(^\circ)$	$r(\mathrm{km})^b$
408 MHz	64.4 ± 0.2	5.5 ± 0.1	199.9 ± 0.6	355.0 ± 1.5	6.2 ± 0.1	446.6 ± 2.0
	14.3 ± 6.6	1.9 ± 0.4	22.3 ± 6.6	39.7 ± 11.6	1.7 ± 0.5	33.7 ± 15.2
	0	1.4	13	23	1.0	11.7
610 MHz	59.2 ± 0.1	5.1 ± 0.1	171.2 ± 0.4	304.8 ± 0.7	5.7 ± 0.1	380.8 ± 0.9
	20.3 ± 1.3	2.2 ± 0.1	31.9 ± 1.8	56.7 ± 3.2	2.2 ± 0.1	56.0 ± 4.2
	0	1.4	13	23	1.0	11.7
800 MHz	55.8 ± 0.4	4.9 ± 0.1	153.9 ± 1.5	274.0 ± 2.6	5.4 ± 0.1	340.5 ± 3.5
	25.1 ± 1.2	2.5 ± 0.1	41.8 ± 2.0	74.5 ± 3.7	2.6 ± 0.1	79.3 ± 4.8
	0	1.4	13	23	1.0	11.7
925 MHz	55.9 ± 0.3	4.9 ± 0.1	154.4 ± 1.0	274.8 ± 2.0	5.4 ± 0.1	341.6 ± 2.6
	26.4 ± 1.5	2.6 ± 0.1	45.0 ± 2.6	80.0 ± 4.8	2.7 ± 0.1	86.5 ± 6.3
	0	1.4	13	23	1.0	11.7
1.33 GHz	52.2 ± 0.6	4.6 ± 0.1	137.0 ± 2.0	243.2 ± 3.7	5.1 ± 0.1	300.2 ± 4.9
	24.3 ± 1.1	2.5 ± 0.1	40.2 ± 1.8	71.3 ± 3.3	2.5 ± 0.1	75.1 ± 4.3
	0	1.4	13	23	1.0	11.7
1.408 GHz	50.9 ± 0.3	4.5 ± 0.1	130.7 ± 0.9	232.5 ± 1.8	5.0 ± 0.1	286.2 ± 2.4
	25.7 ± 0.7	2.6 ± 0.1	43.4 ± 1.2	77.0 ± 2.2	2.7 ± 0.1	82.6 ± 3.3
	0	1.4	13	23	1.0	11.7
1.64 GHz	52.0 ± 0.7	4.6 ± 0.1	135.7 ± 2.3	241.5 ± 4.3	5.1 ± 0.1	298.0 ± 5.7
	27.6 ± 2.2	2.7 ± 0.2	48.1 ± 4.2	85.3 ± 7.4	2.8 ± 0.2	93.4 ± 9.7
	0	1.4	13	23	1.0	11.7

Zhang, Qiao, Han, Lee, Wang , AA,2007

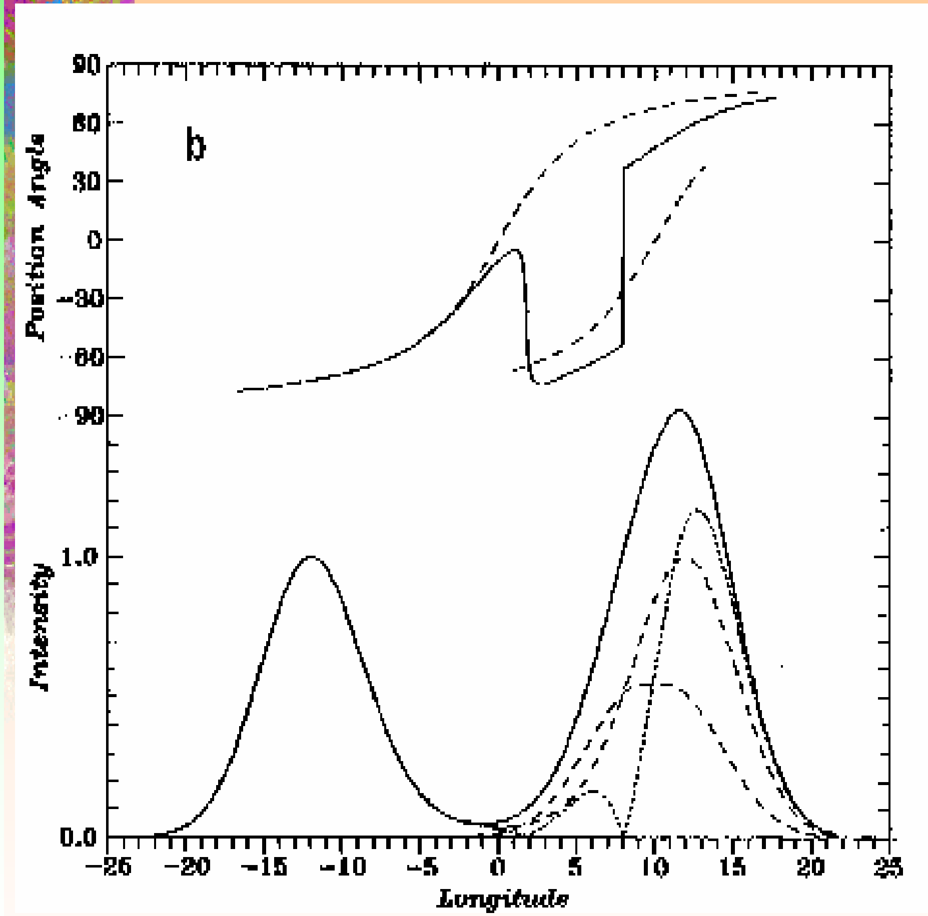
Polarization: Beam shift→PA jumps

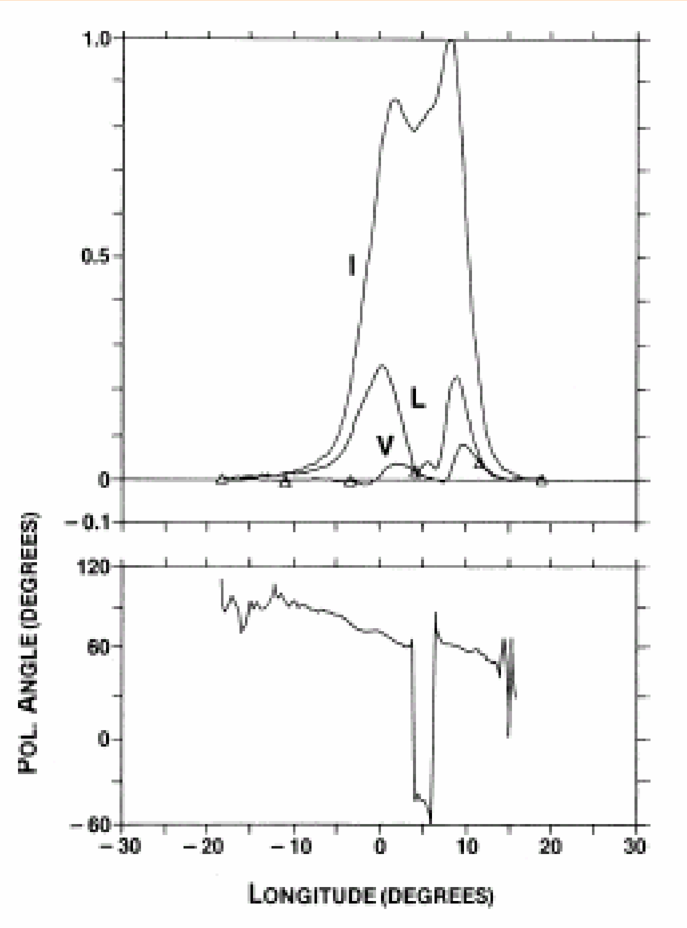




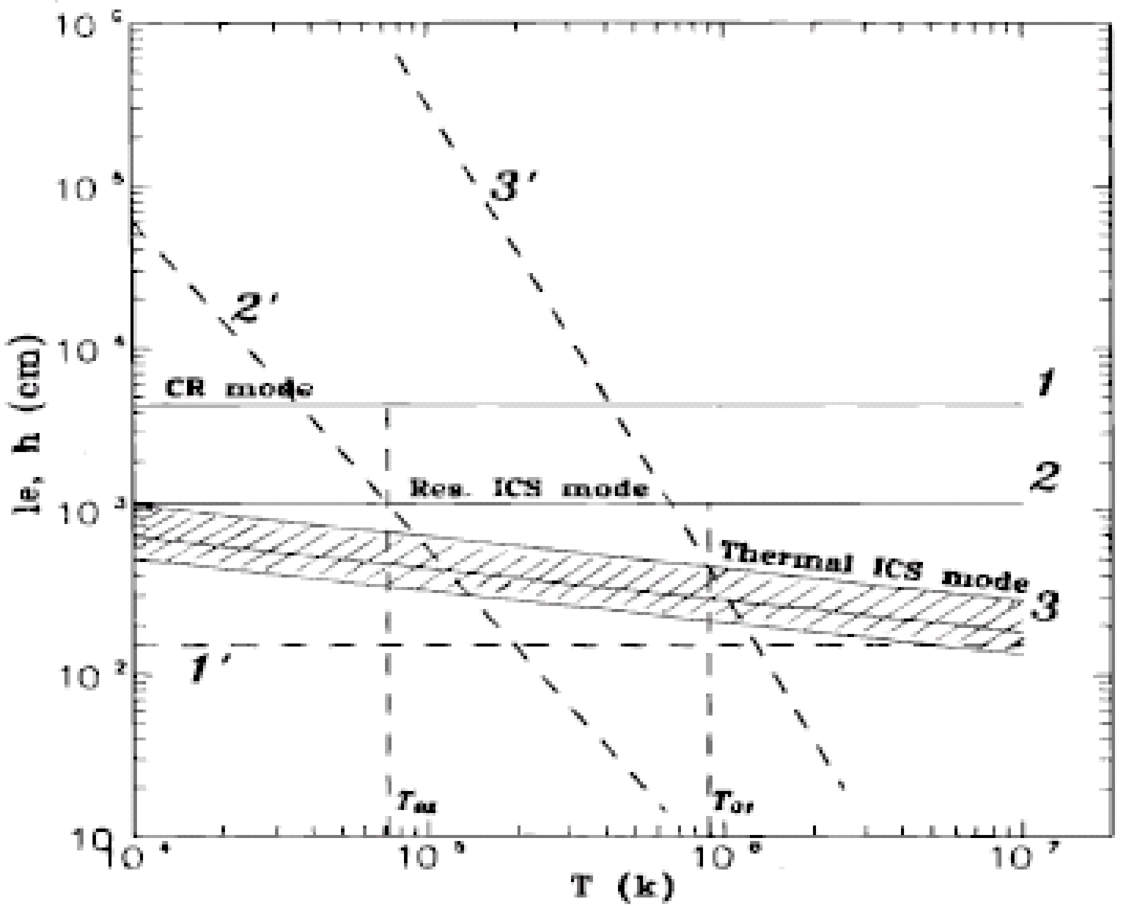
Xu, Qiao & Han, 1997, AA

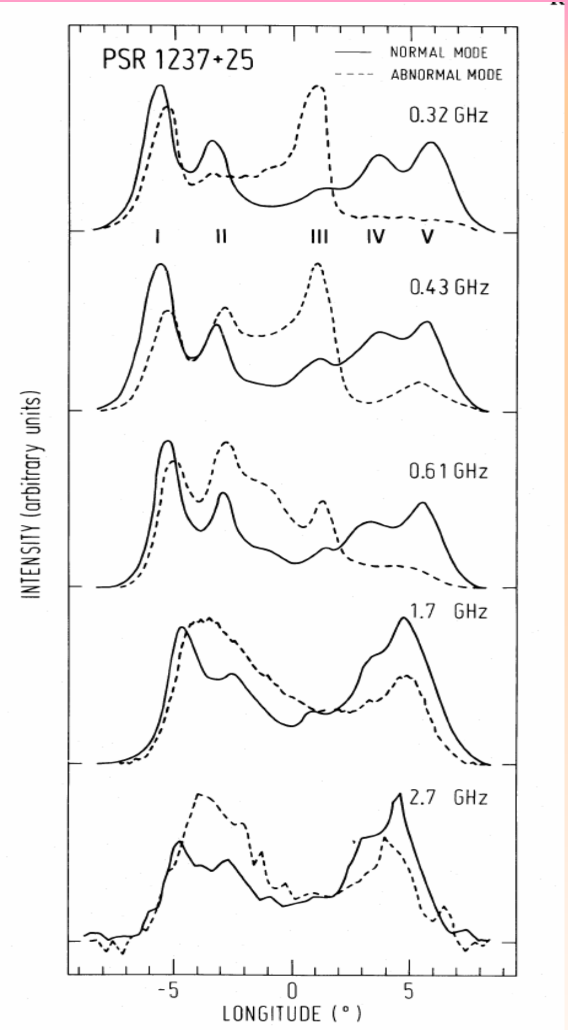
Polarization: PA jump





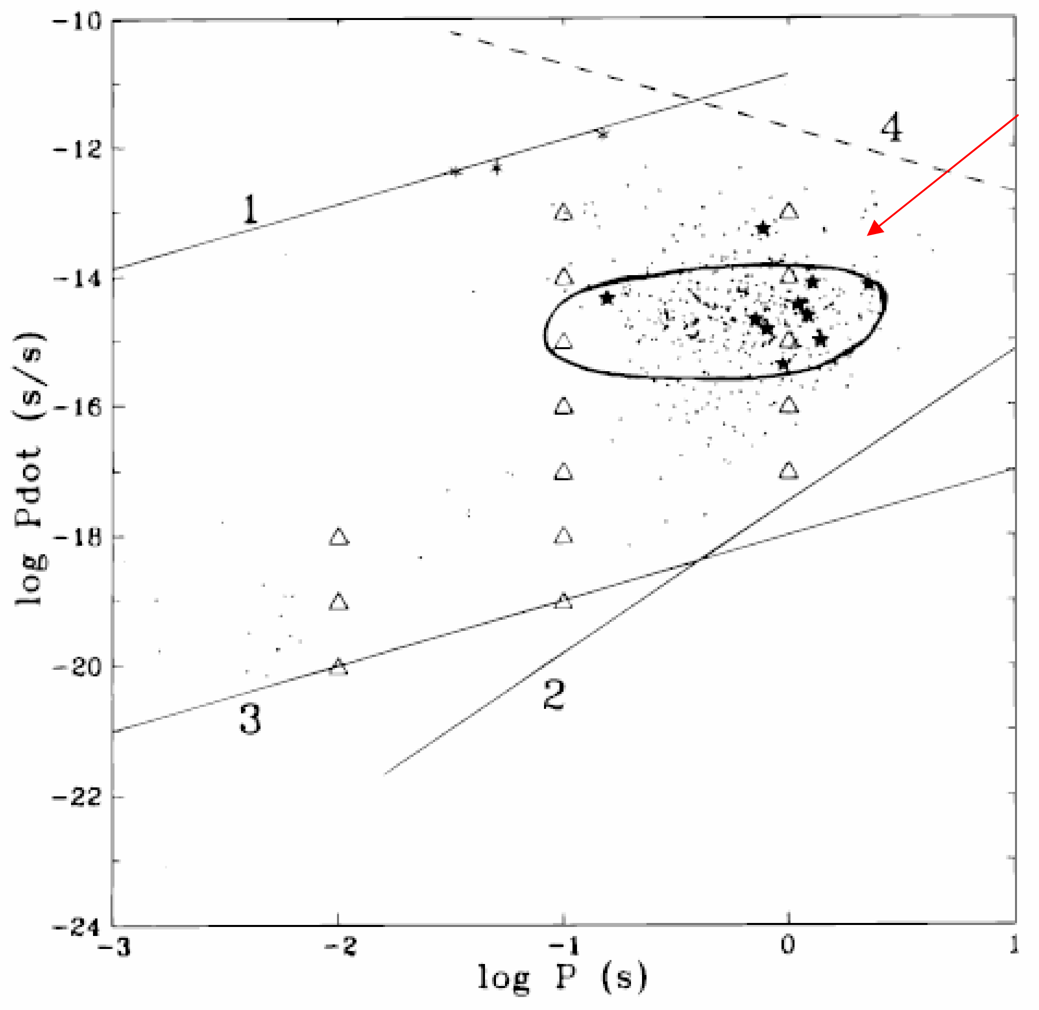
Xu, Qiao & Han, 1997, AA





Zhang,Qiao,Lin,Han, 1997

Rankin, 1986



Mode change pulsars

Zhang,Qiao,Lin,Han,

1997,ApJ
Zhang,Qiao, Han, 1997,ApJ

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5、伽玛射线辐射与射电如何统一研究？

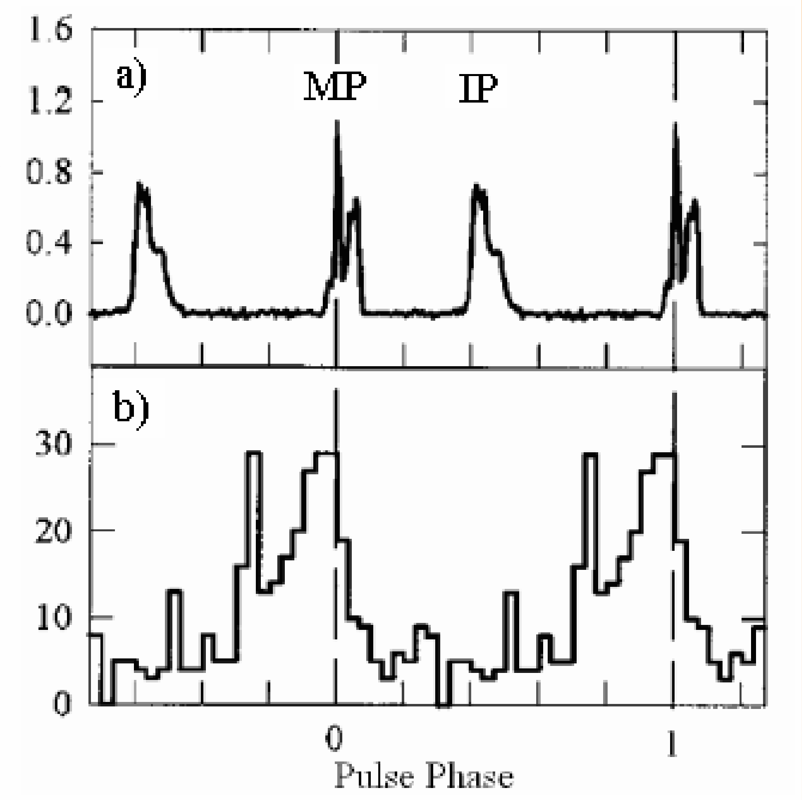
PSR B1055-52 :
observational constraints

- 1). Inclination angle
- α=74.7 dgree
- 2). Viewing angle
- ζ =114 dgree

Observed emission beams

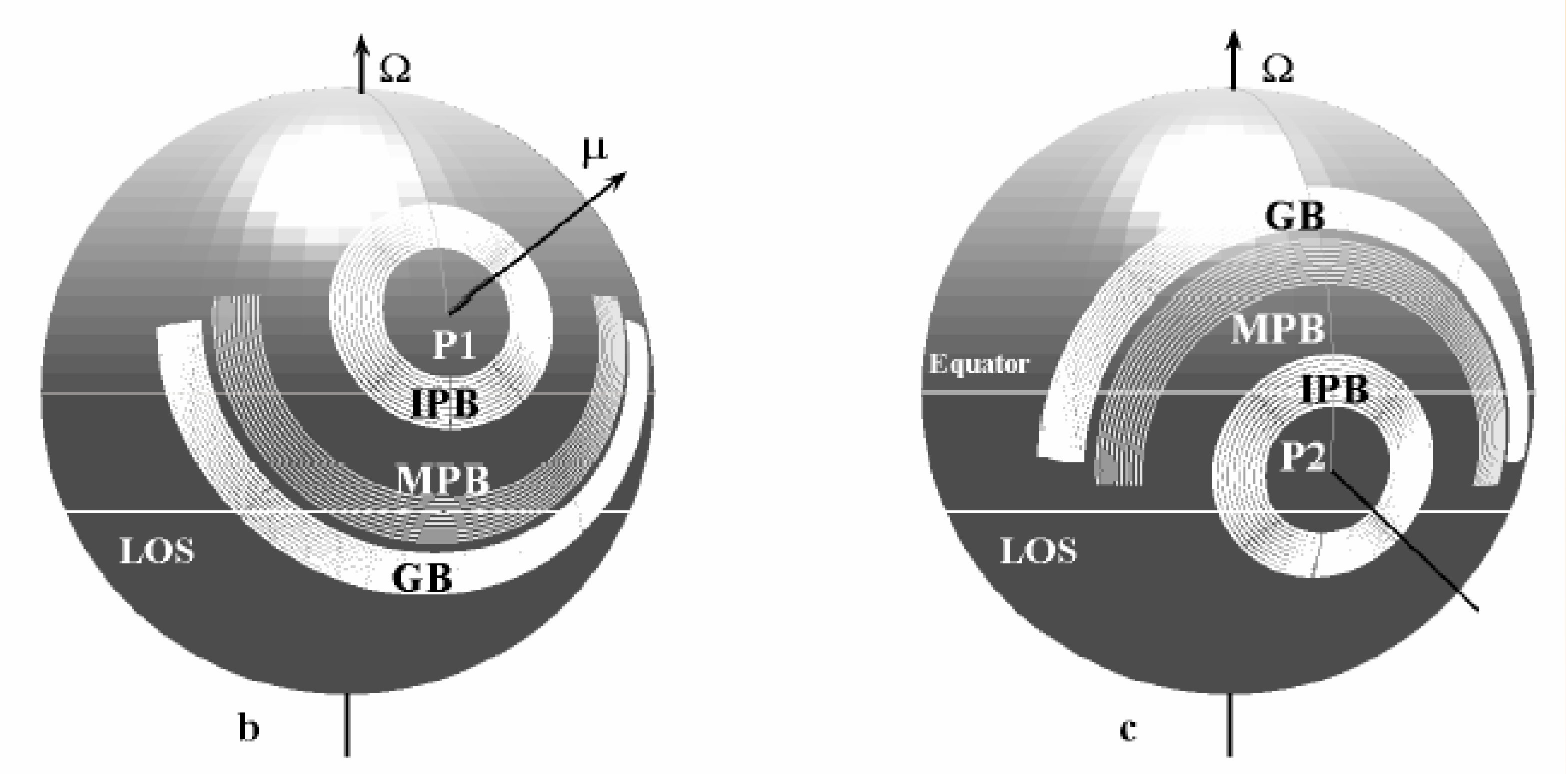
Radio

Gamma-ray



Thompson et al. 1992

Observed emission beams

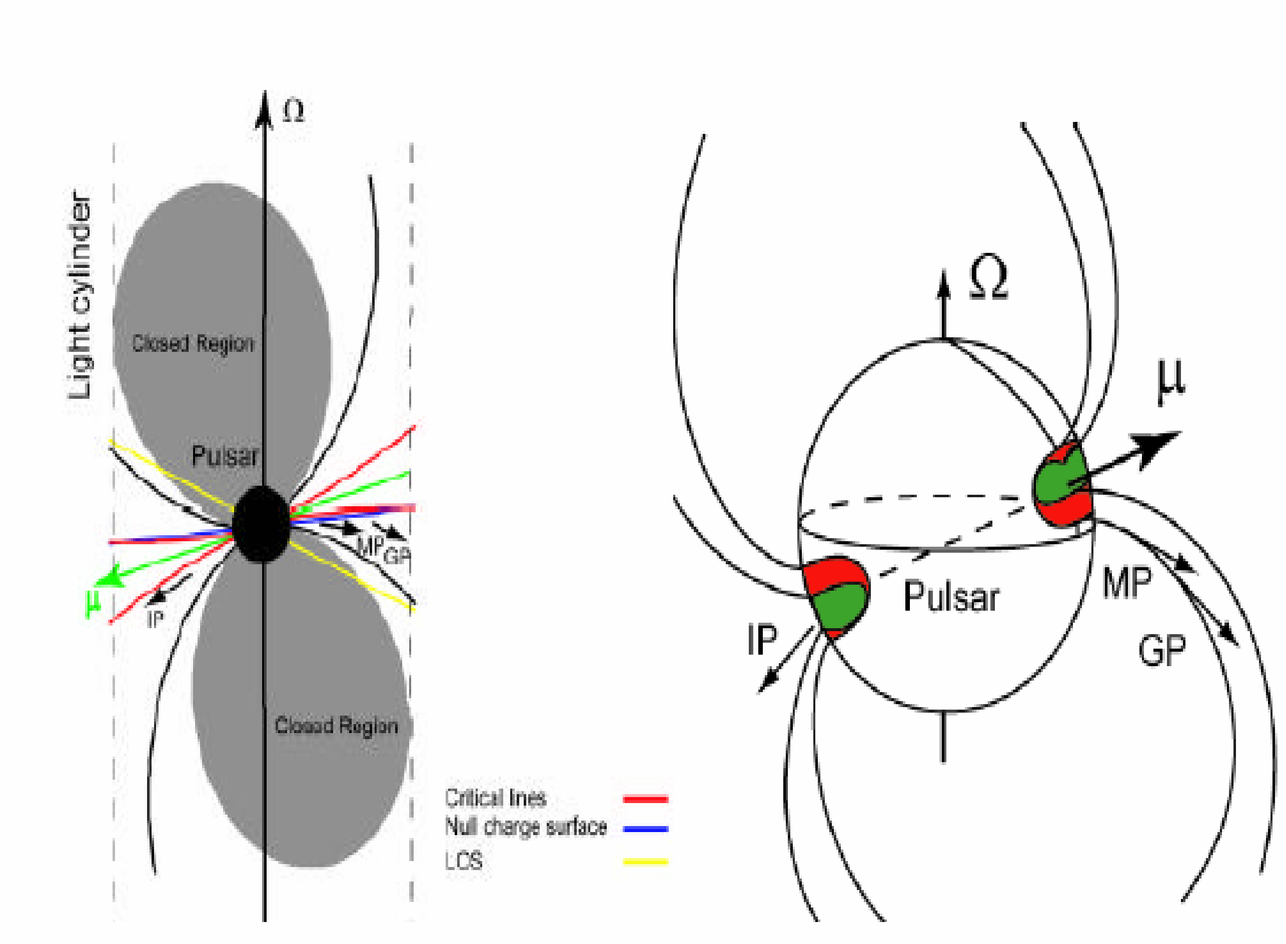


From observation, the radiation location can be determined uniquely for this star.

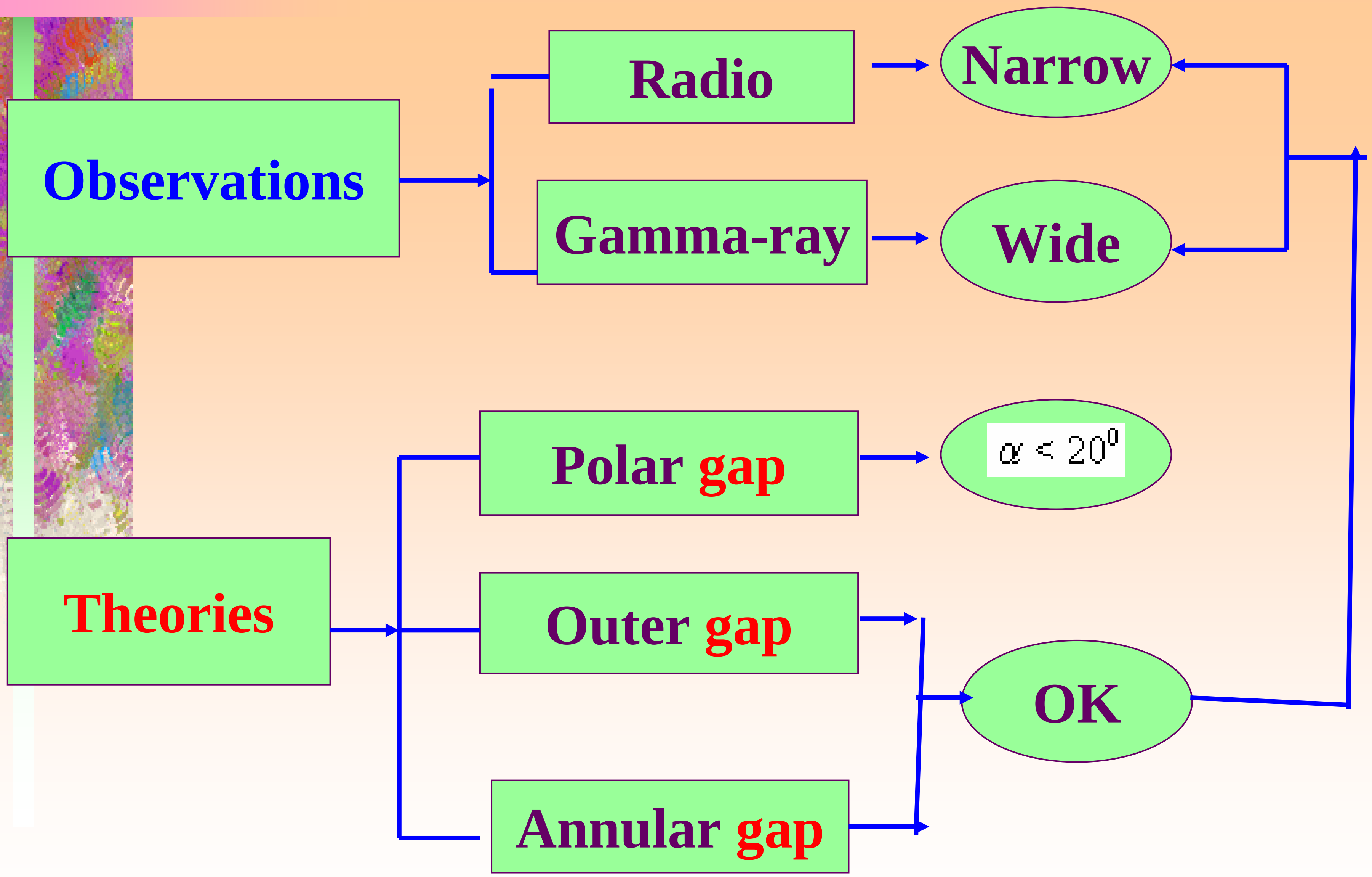
Wang et al.2005

Annular & outer gap model

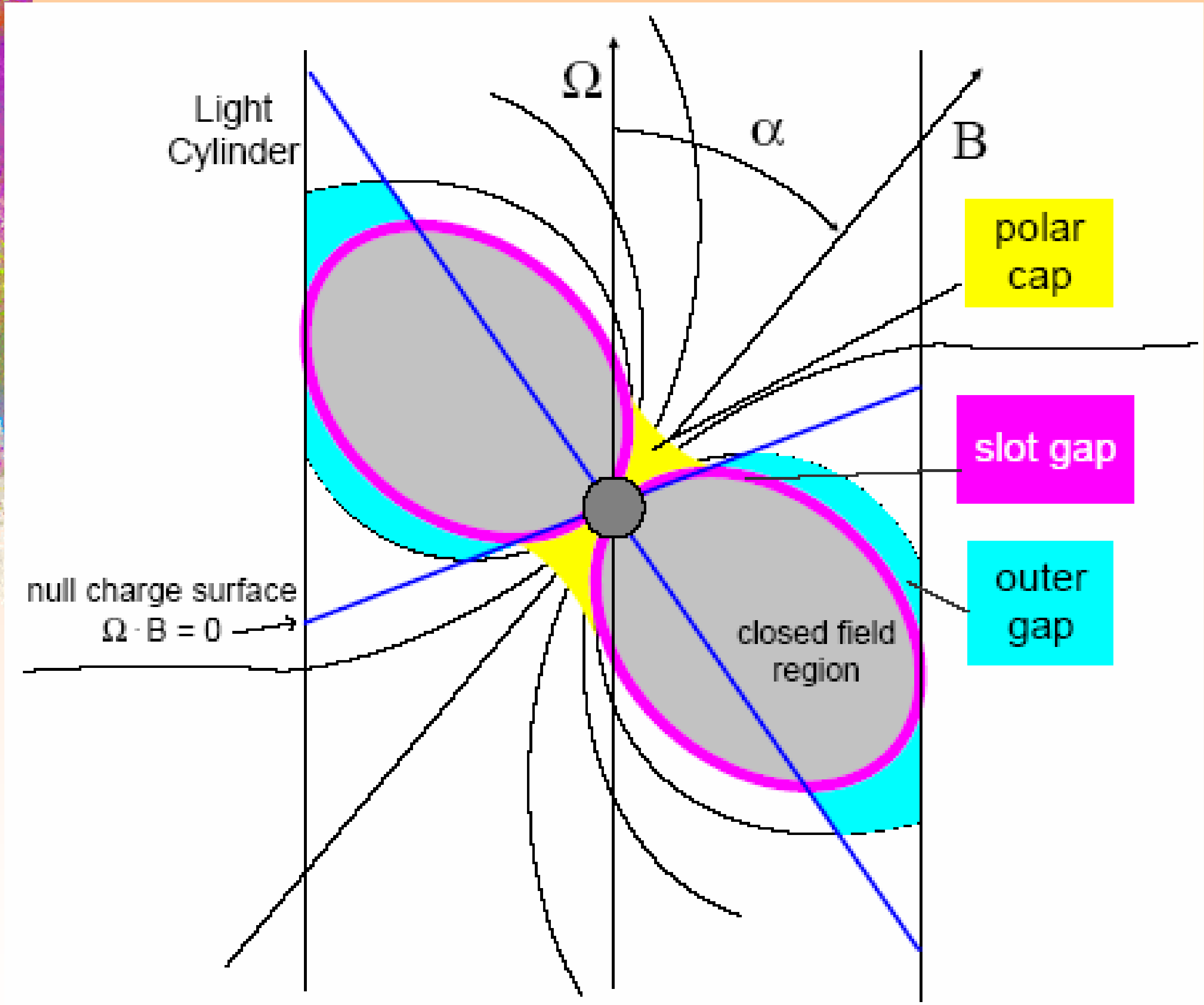
The observations show that the radiation position locates in the annular region.



Wang et al.2005

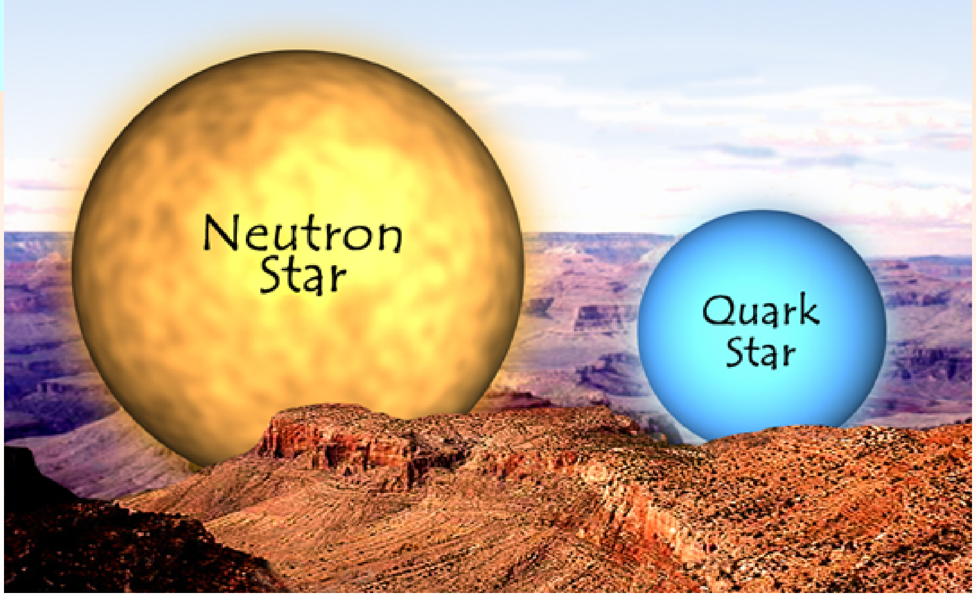

Observations
Radio
Gamma-ray
Narrow
Wide
Theories
Polar gap
Outer gap
Annular gap
$\alpha < 20^0$
OK

Slot gap？


Light
Cylinder
Ω
α
B
polar
cap
slot gap
outer
gap
null charge surface
Ω · B = 0
closed field
region

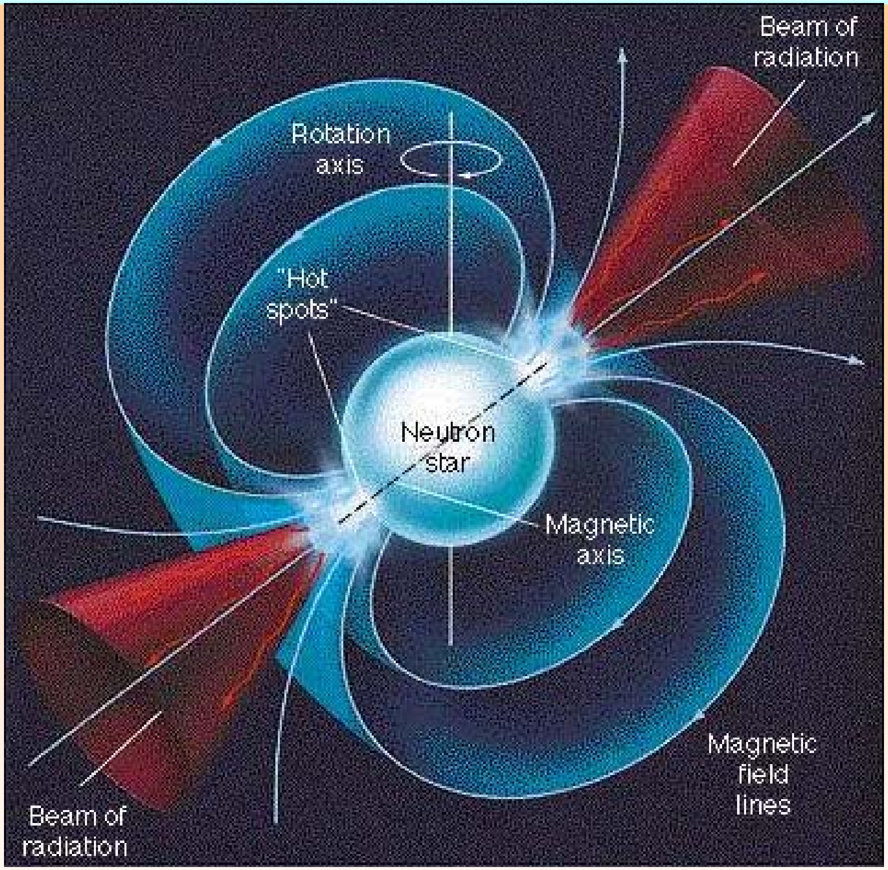
Future obs. & theories

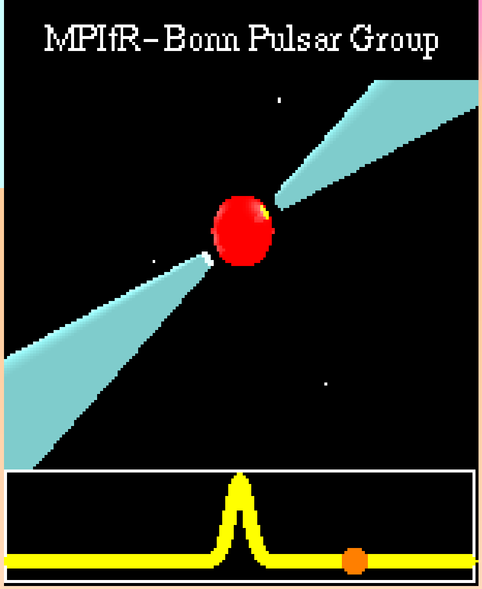
- Pulsars: NS or Quark stars ?
- Free flow: sparking or not ?
- Free flow: can produce drifting sub-pulse?

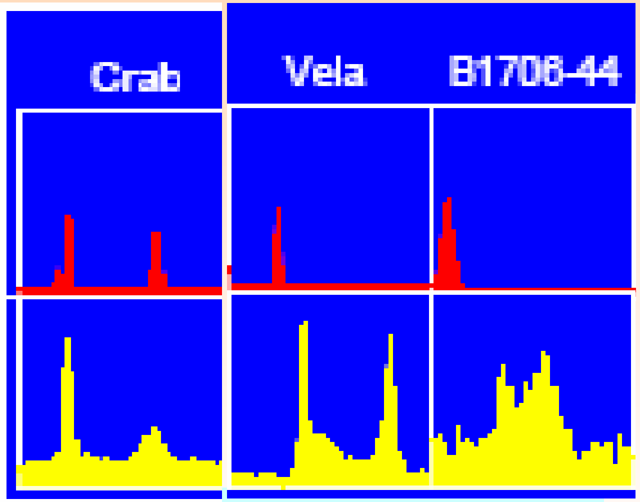


Thank you！

Pulsar radiation







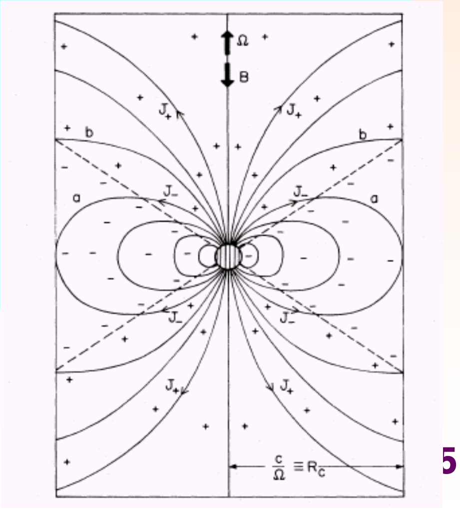
Radio: ♦"3-4%

Gamma-ray: Two pulses & very wide

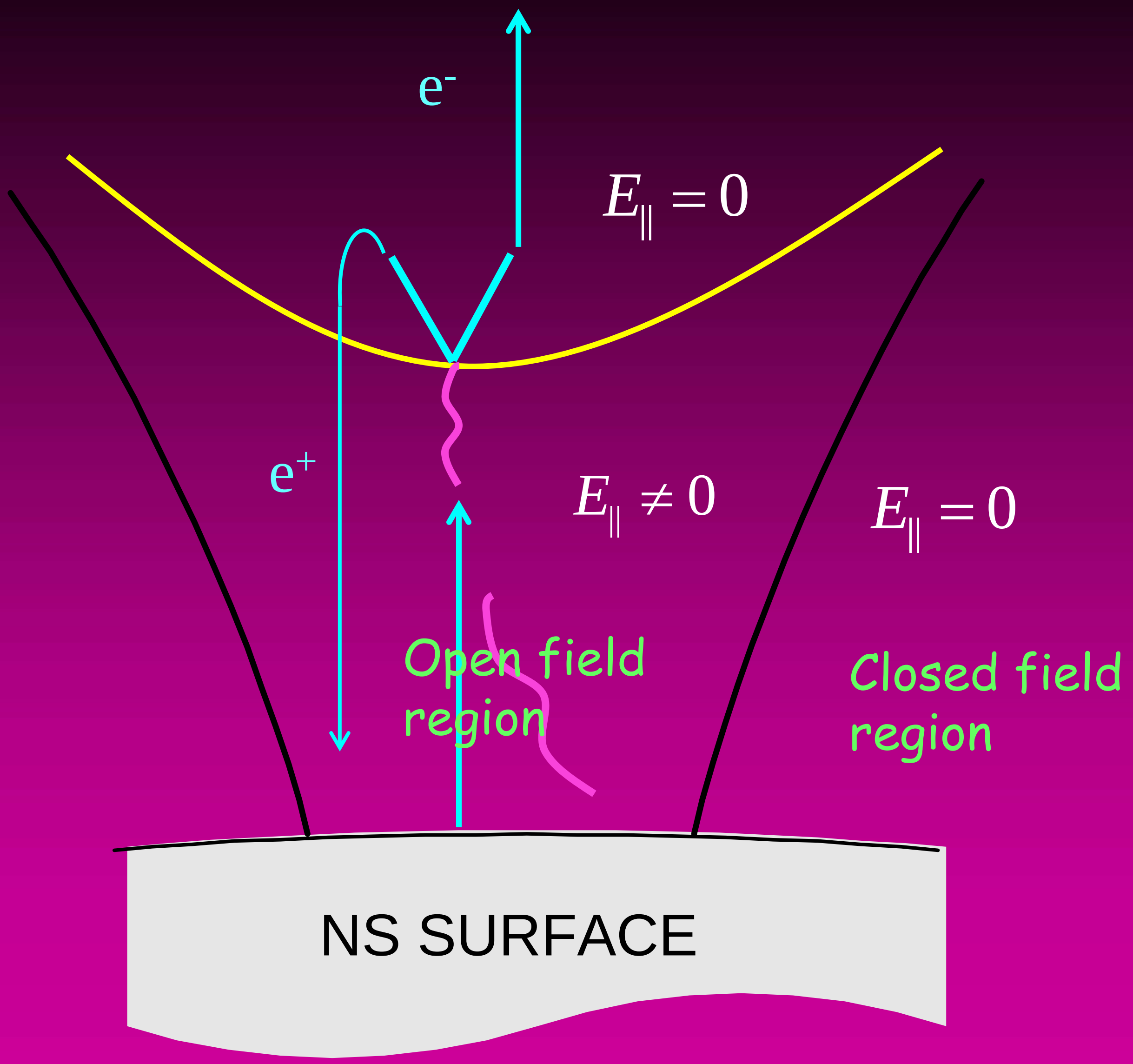
§ 1. *Introduction*

1. *The magnetosphere*
2. Radio & gamma-ray obs.
3. Particle acceleration: $\vec{E}\cdot\vec{B} \neq 0$
   1) Vacuum gap; 2) Free flow

4. Annular gap

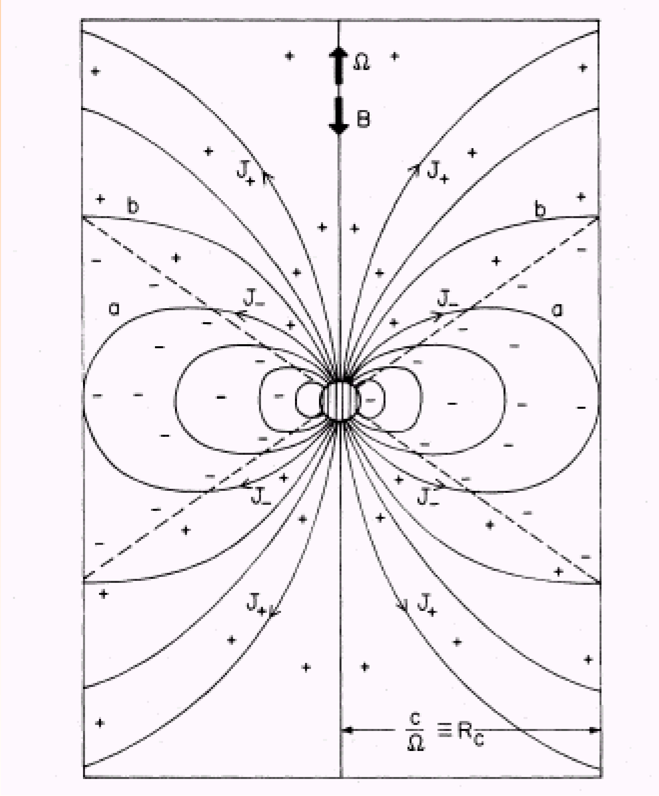


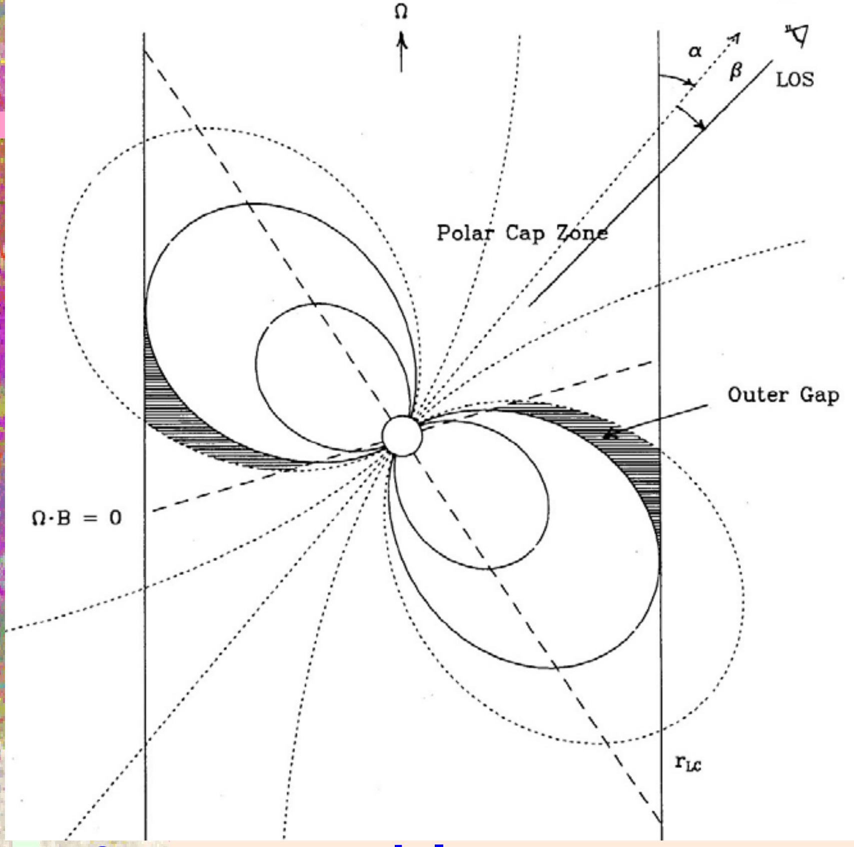
Polar Cap Pair Formation Front

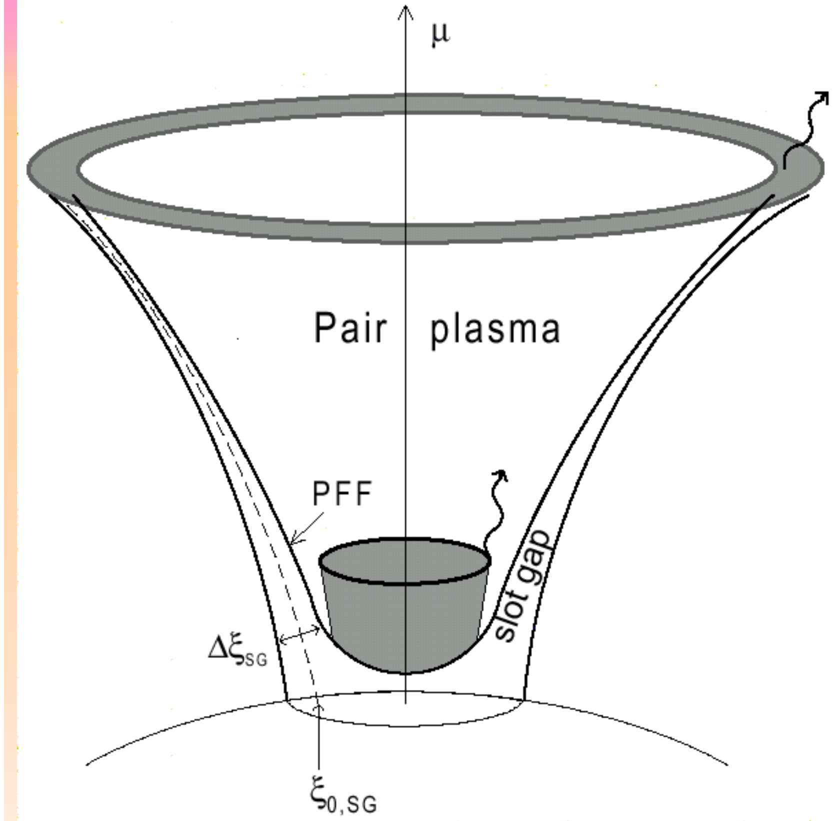


$$\vec{E} + \frac{1}{c}\left(\vec{\Omega} \times \vec{r}\right) \times \vec{B} = 0$$

$$\rho = \rho_+ - \rho_- = -\frac{\vec{\Omega} \cdot \vec{B}}{2\pi c}$$





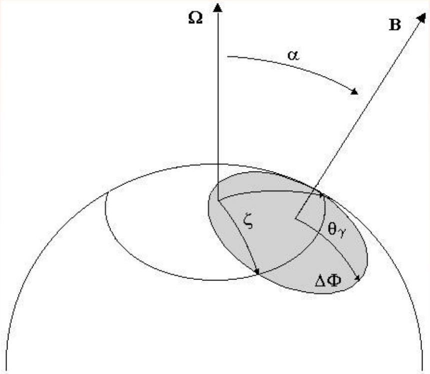


Outer gap model

(外间隙模型)

polar cap model

(极冠模型)



Introduction : two models