Gamma-Ray Light Curves in Offset Polar Cap Geometry

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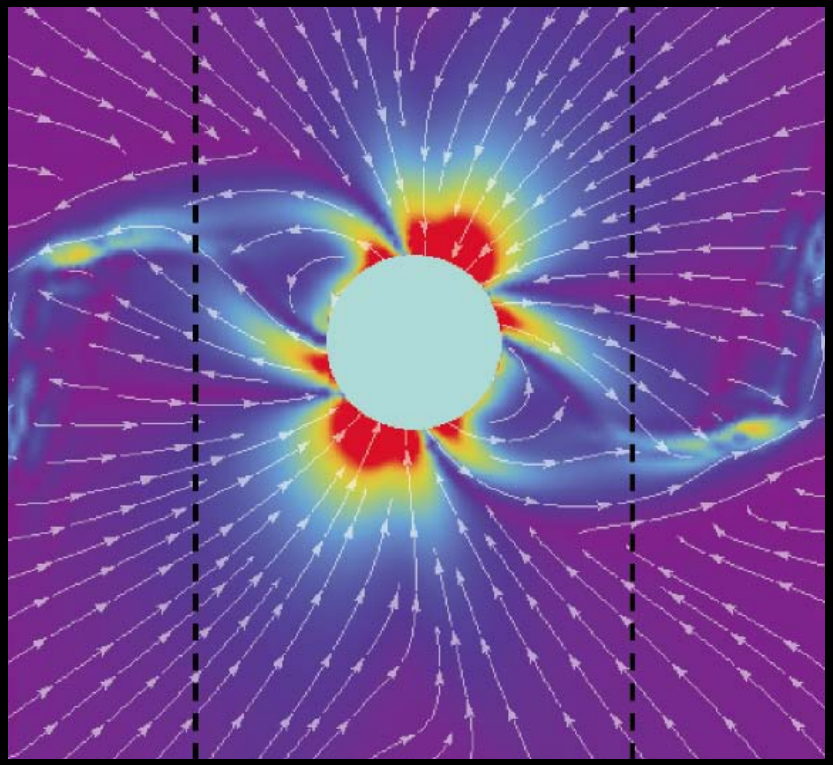
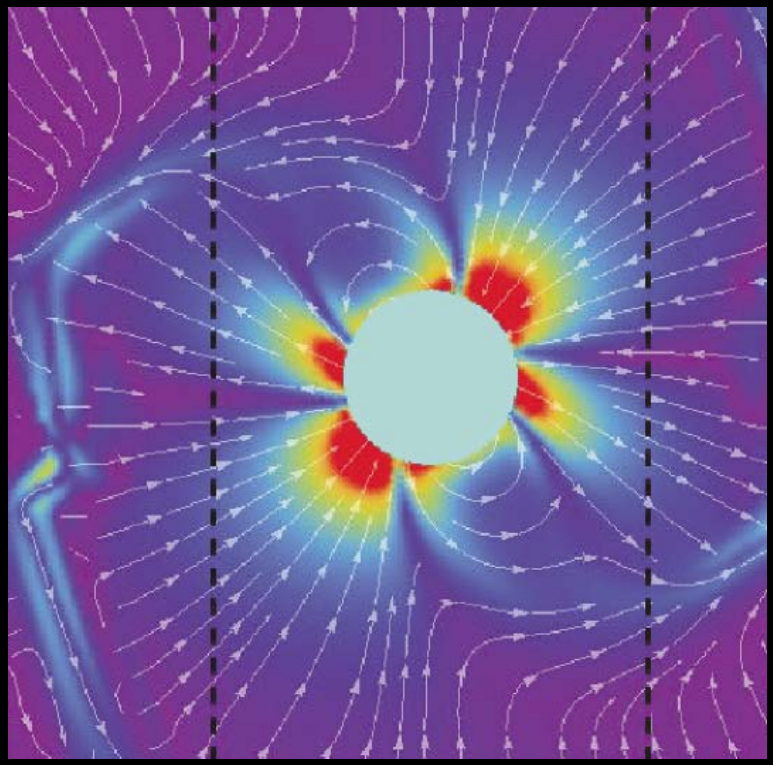
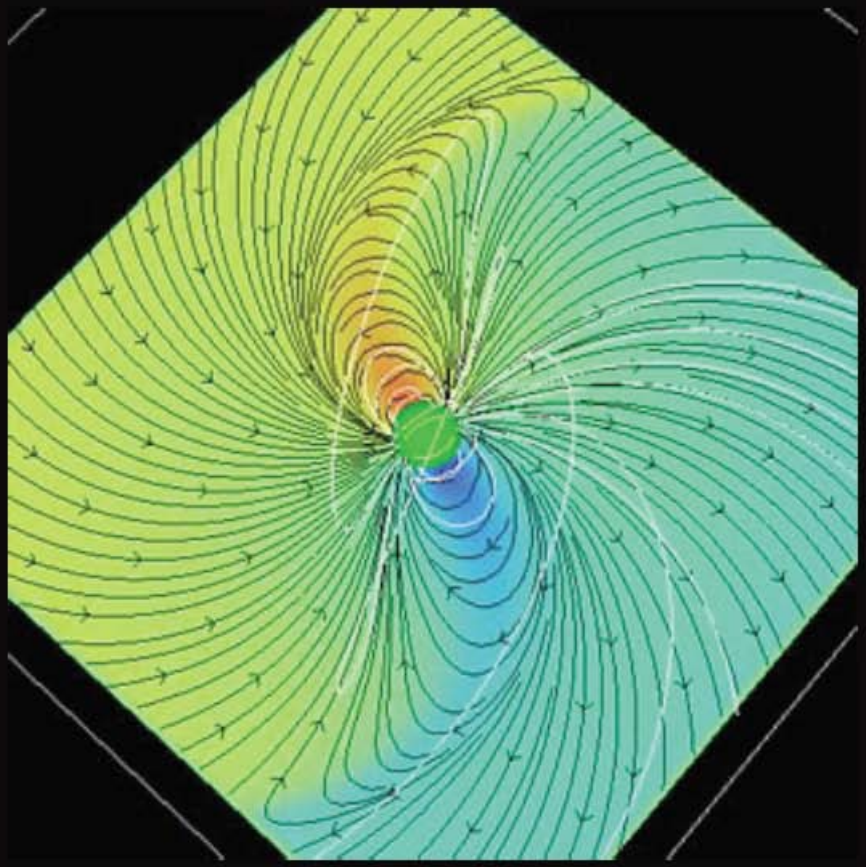


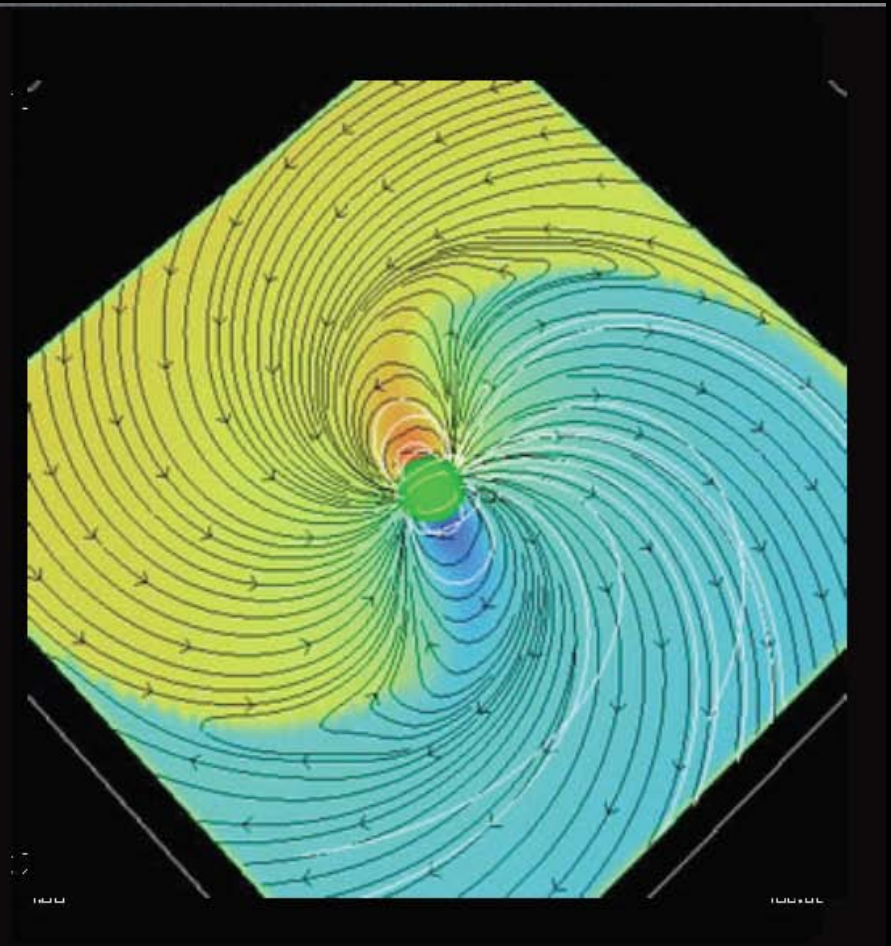


Vacuum vs. force-free magnetospheres

Vacuum
Deustch 1955

Force-free
Spitkovsky 2006

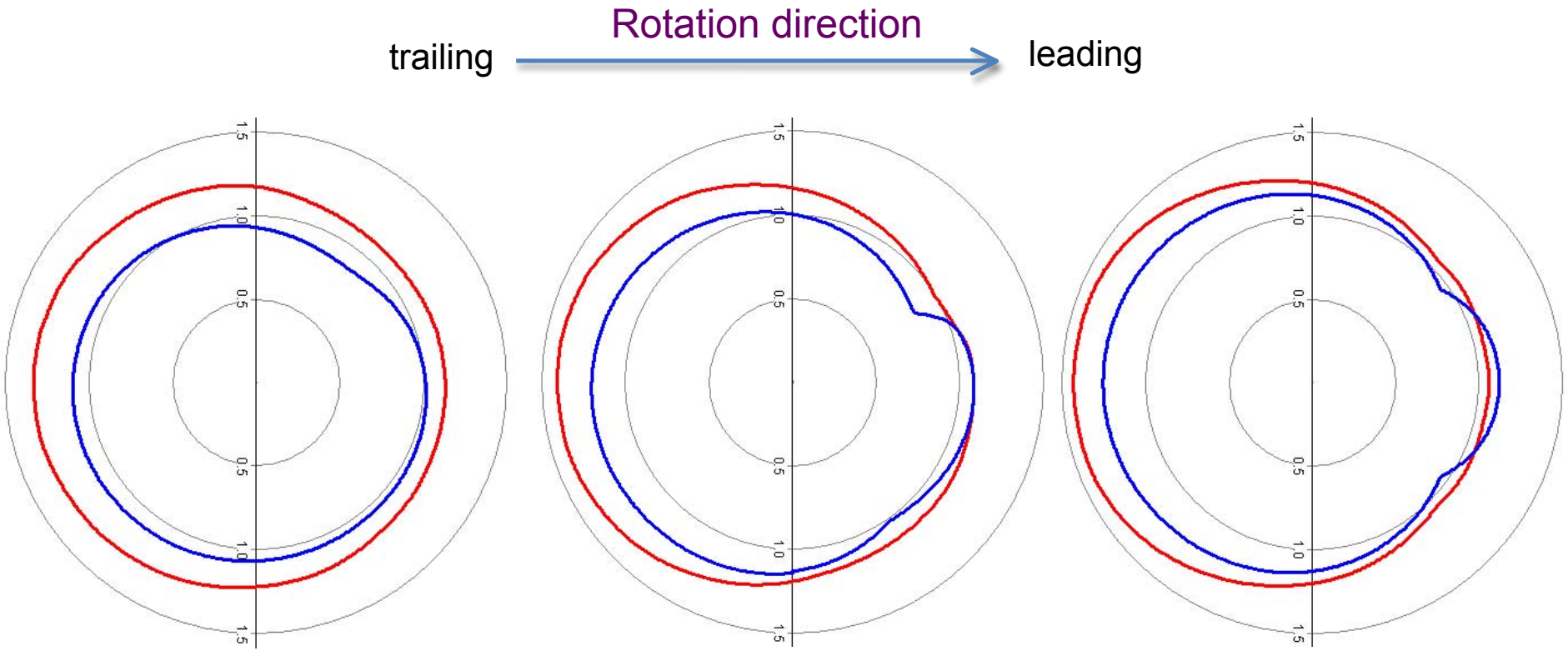




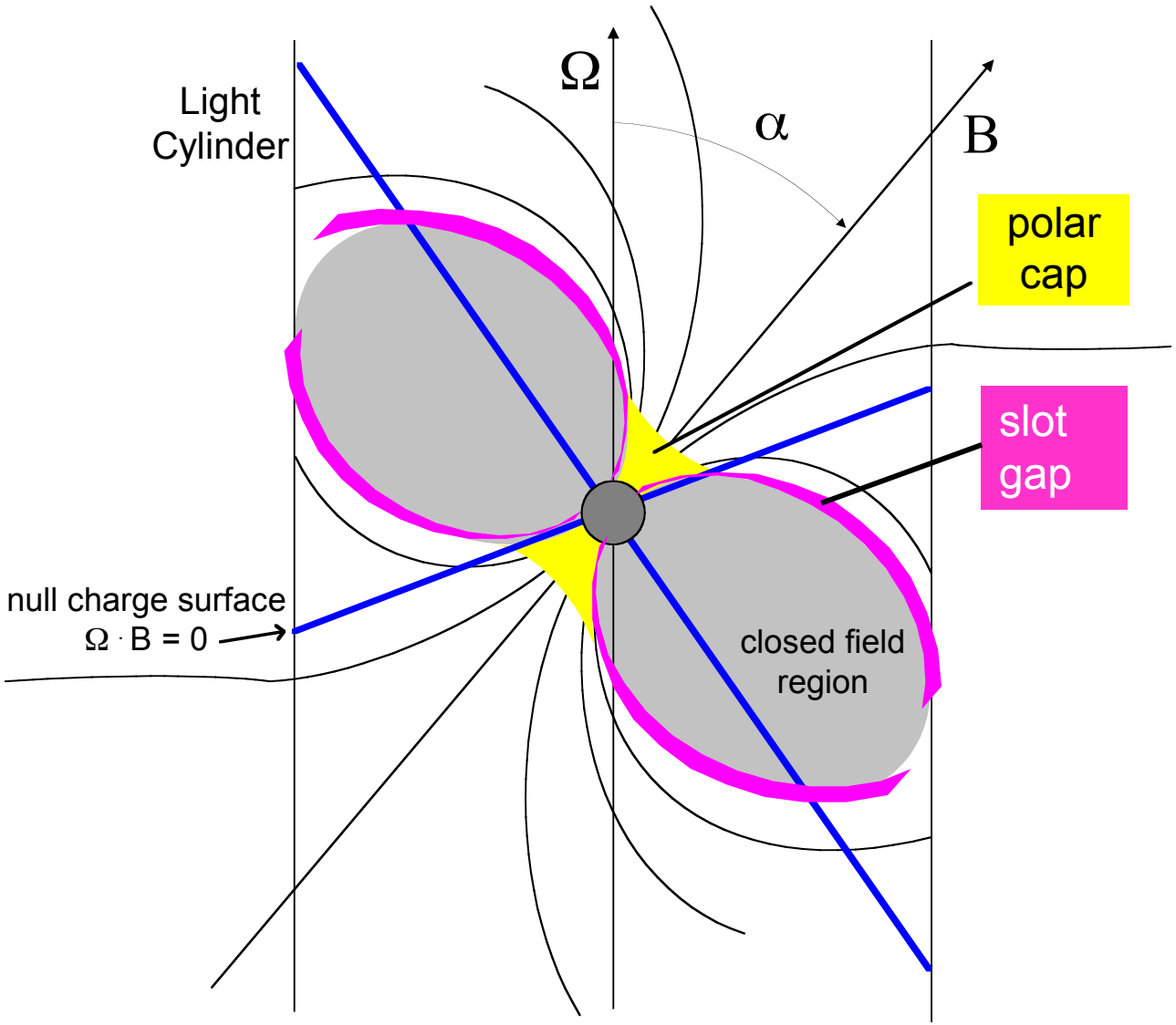
90^0 inclination

A. Spitkovsky

Polar caps in retarded magnetic fields



Slot gap accelerator



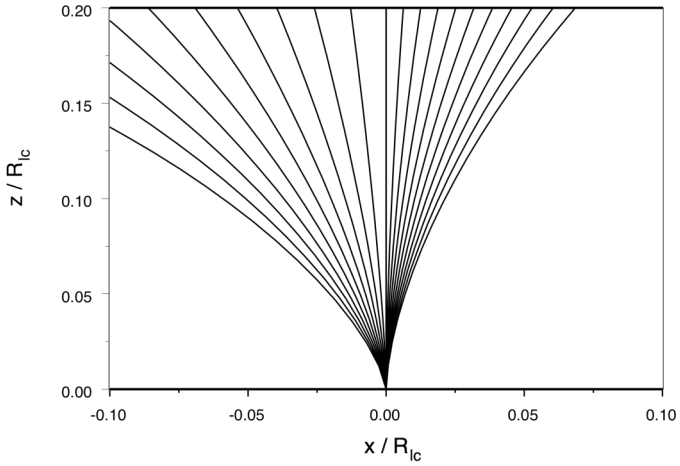
Two main effects from offset PCs:
- Asymmetric $E_{||}$
- geometry of open field lines

- Problem: we don't know the correct $E_{||}$ until we understand pulsar magnetospheres with dissipation
(see poster by Kalapotharakos et al.)
- For now, assume vacuum dipole to estimate $E_{||}$ → emission geometry

- Embed emission geometry in global magnetic field
(see also talk by Venter et al., and posters by Decesar et al., Johnson et al.)

Simple model of offset polar cap

Harding & Muslimov 2011



- Magnetic field

$$B = B_0\left(\frac{r}{R}\right)^3\left[\hat{r}\ \cos[\theta(1+a)] + \hat{\theta}\ \frac{1}{2}\sin[\theta(1+a)]\right]$$

- Field line

$$a = \varepsilon\begin{cases}\cos\phi & \text{Offset in plane of } \mathbf{B}, \boldsymbol{\Omega}\\ \sin\phi & \text{Offset } \perp \text{ to plane of } \mathbf{B}, \boldsymbol{\Omega}\end{cases}$$

$$\theta = \frac{1}{(1+a)}\sin^{-1}\left\{\xi\cos\left(\frac{\pi}{2}a\right)\ x^{(1+a)/2}\right\} \qquad x = \frac{r}{R_{LC}}, \qquad \xi = \frac{\theta_0}{\theta_{PC}}, \qquad \theta_{PC} = \left(\frac{\Omega R}{c}\right)^{1/2}$$

- Effective offset is a fraction of polar cap radius

$$\Delta r(\varepsilon) \approx R\theta_{PC}[1-\theta_{PC}^{\varepsilon}] \approx R\theta_{PC}[1-\varepsilon\theta_{PC}]$$

Small fraction of NS radius

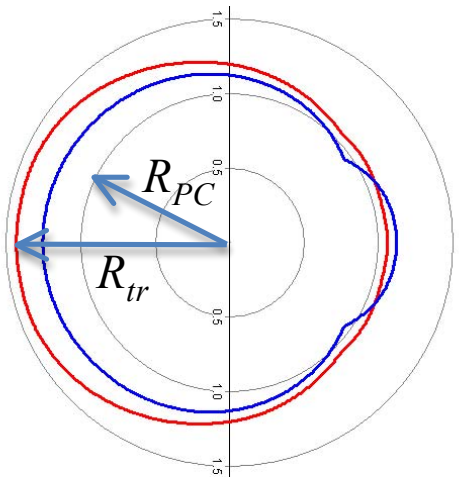
Accelerating electric field in slot gap

- Offset introduces large asymmetry in particle acceleration across PC

$\varepsilon \cos\phi > 0$ Smaller PC angle, reduced $E_{||}$

$\varepsilon \cos\phi < 0$ Larger PC angle, increased $E_{||}$

- Offset is not a free parameter in magnetosphere models with retardation

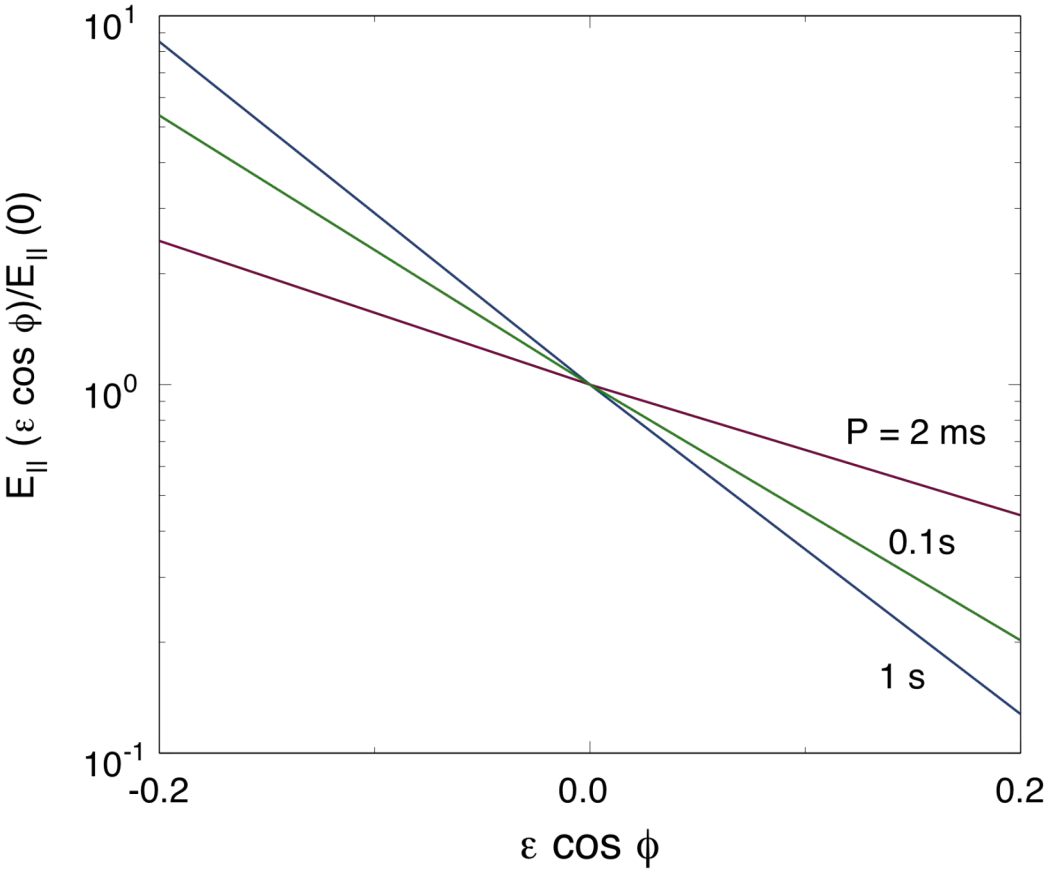


$$\theta_{PC}^{-\varepsilon} \approx \left(\frac{R_{tr}}{R_{PC}} \right)$$

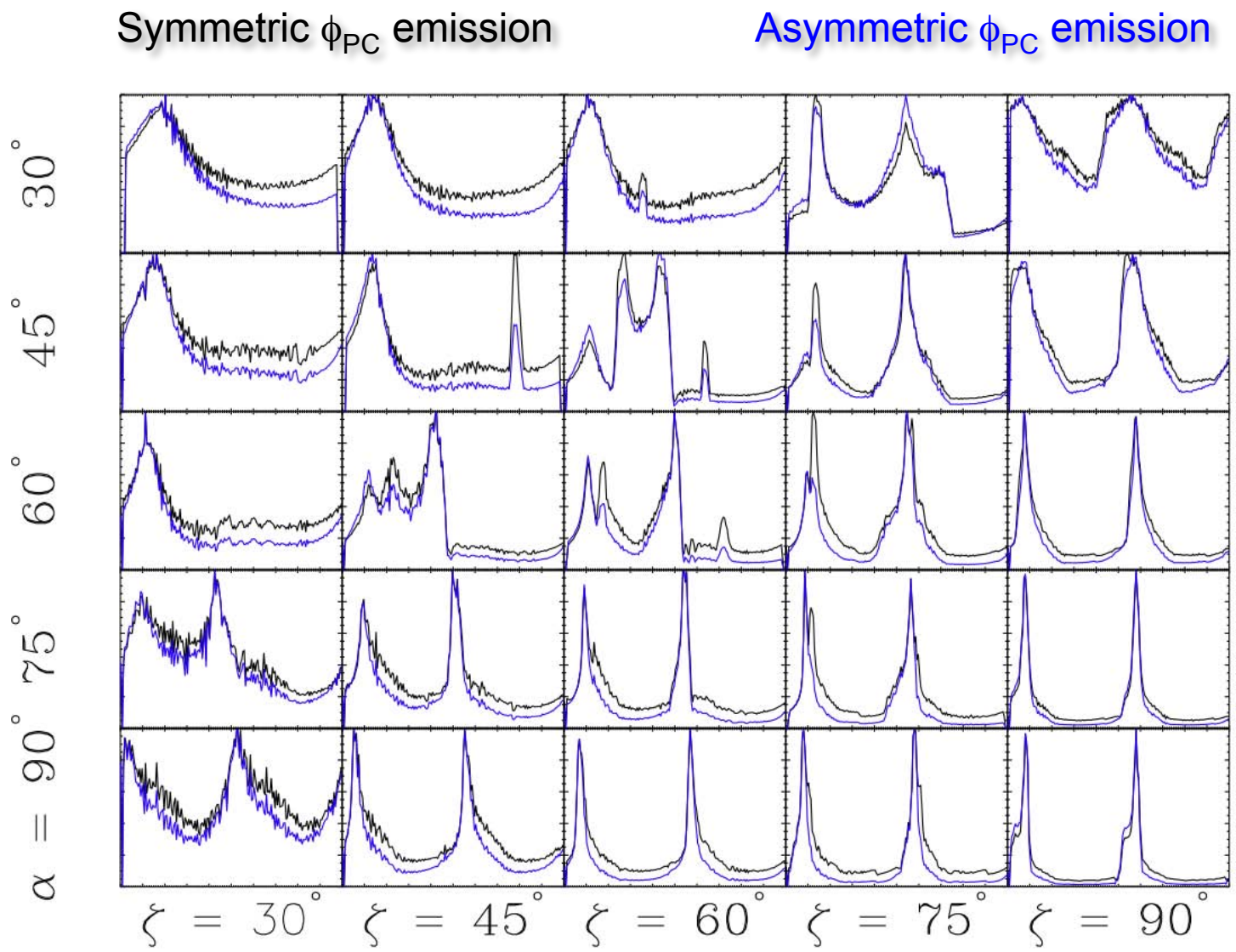
α-dependent

$$E_{||}(\varepsilon \cos\phi) \approx \frac{\theta_{PC}^{2\varepsilon \cos\phi}}{(1+\varepsilon \cos\phi)^2} E_{||}(0)$$

Vacuum dipole: ε ~ 0.05 – 0.1
Force-free: ε ~ 0.1 – 0.2



Slot gap light curves for vacuum dipole geometry



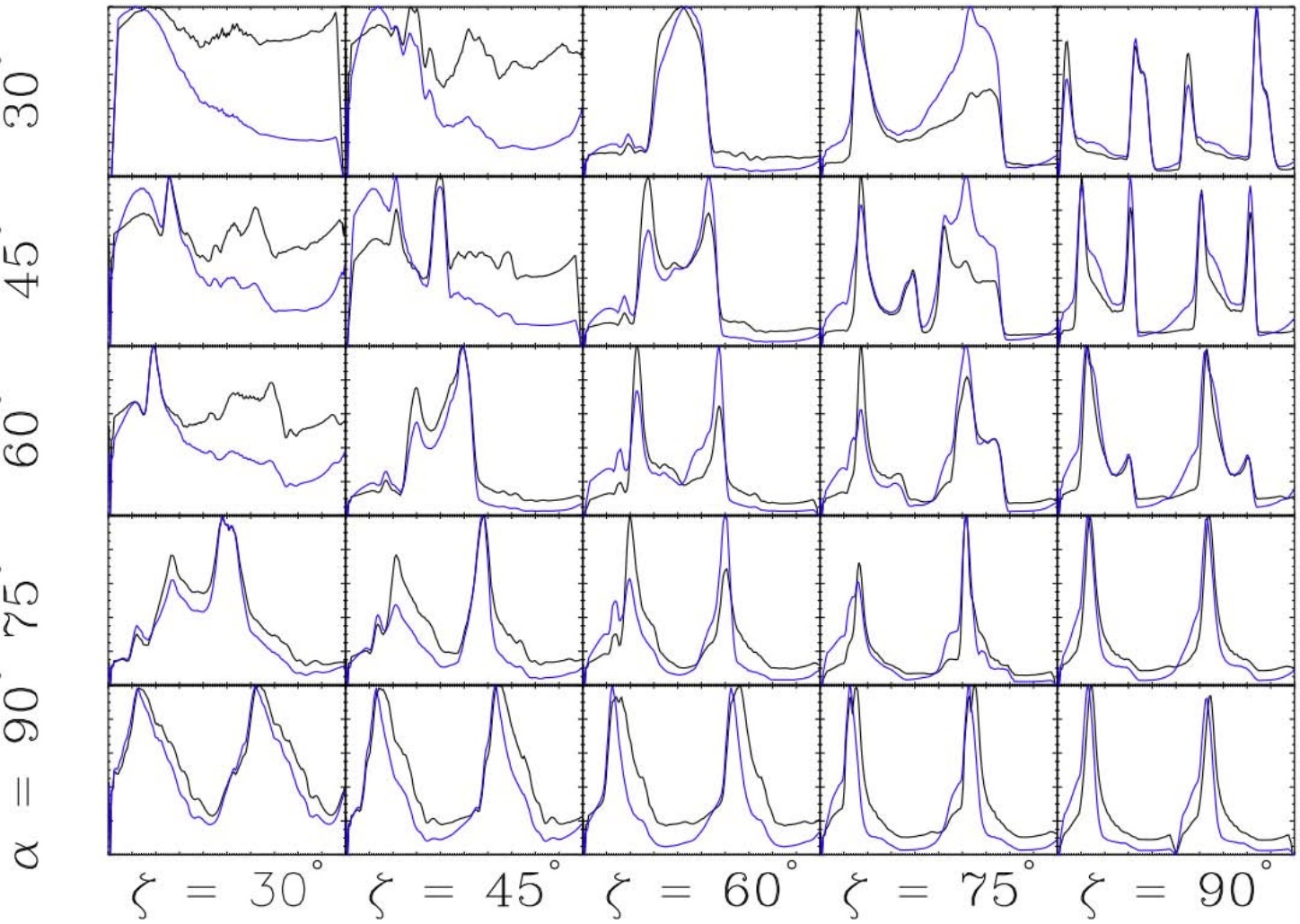
Gap width: 0.05
Max radius: $1.2R_{lc}$
Max cyl. radius: $0.95R_{lc}$

Higher SG emission on trailing field lines enhances peak-to-off-peak contrast

Slot gap light curves for force-free geometry

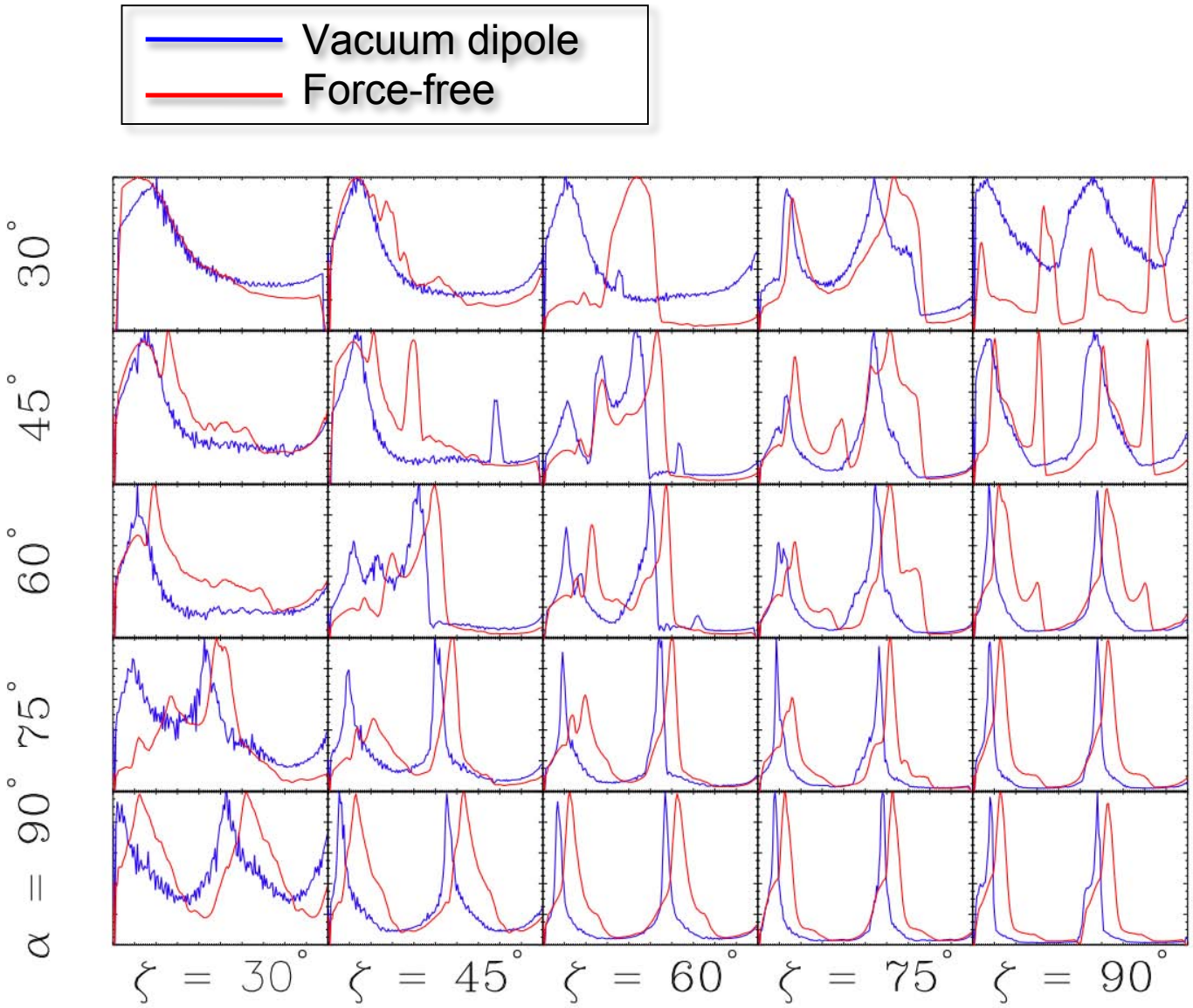
Symmetric ϕ_{PC} emission

Asymmetric ϕ_{PC} emission



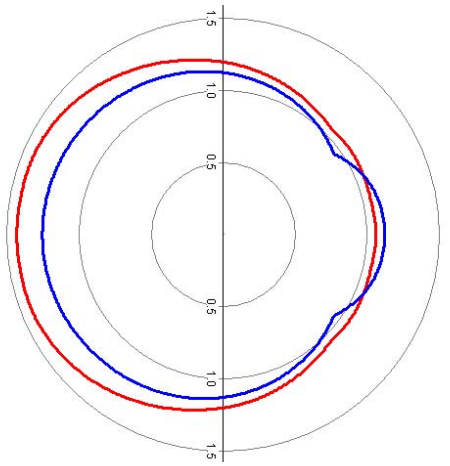
Gap width: 0.05
Max radius: $1.2R_{lc}$
Max cyl. radius: $0.95R_{lc}$

Slot gap light curves: vacuum vs. force-free

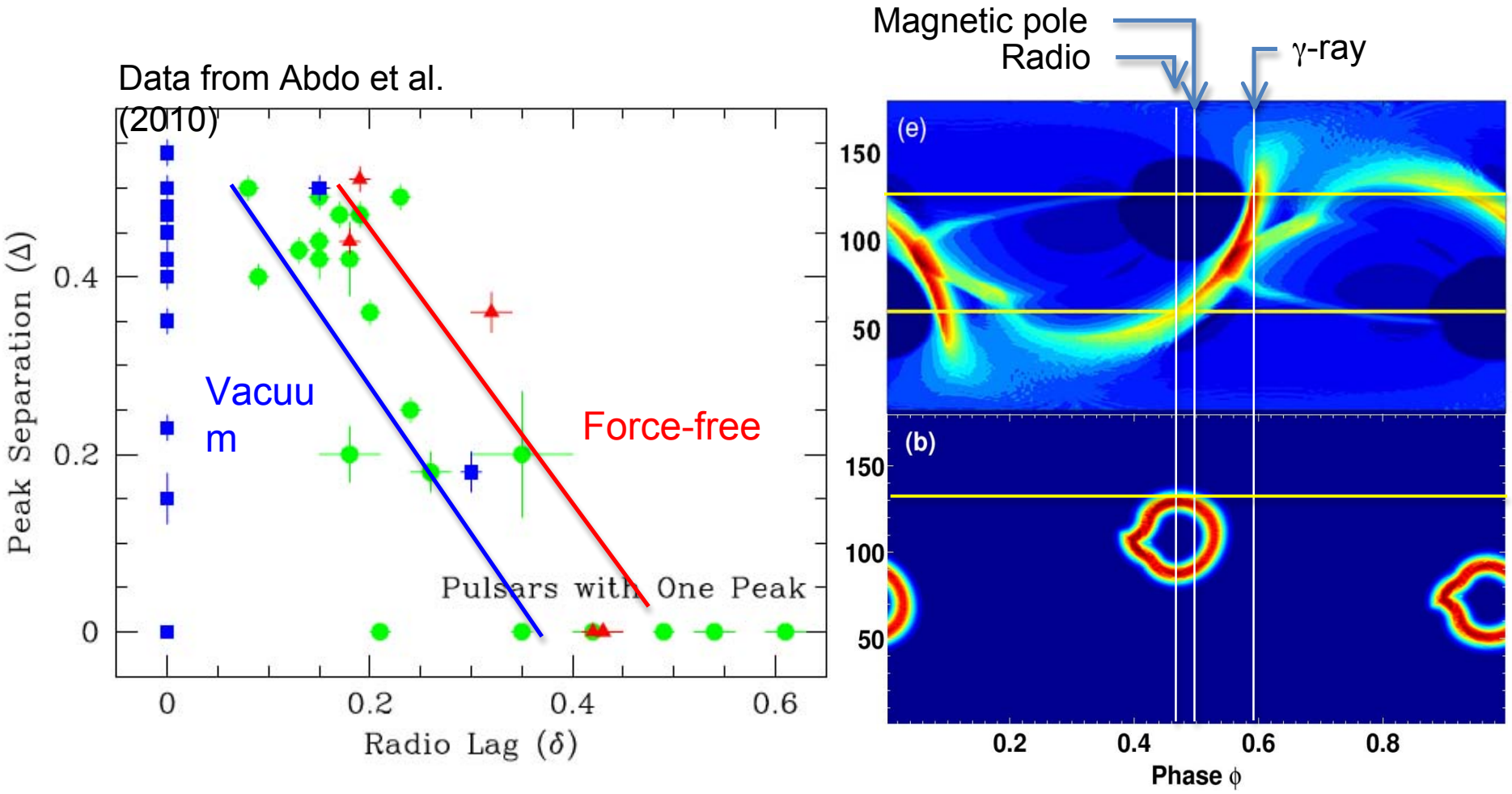


Force-free LC peaks occur at later phase by .05 – .15 due to:

- Larger PC
- Later phase of trailing field lines



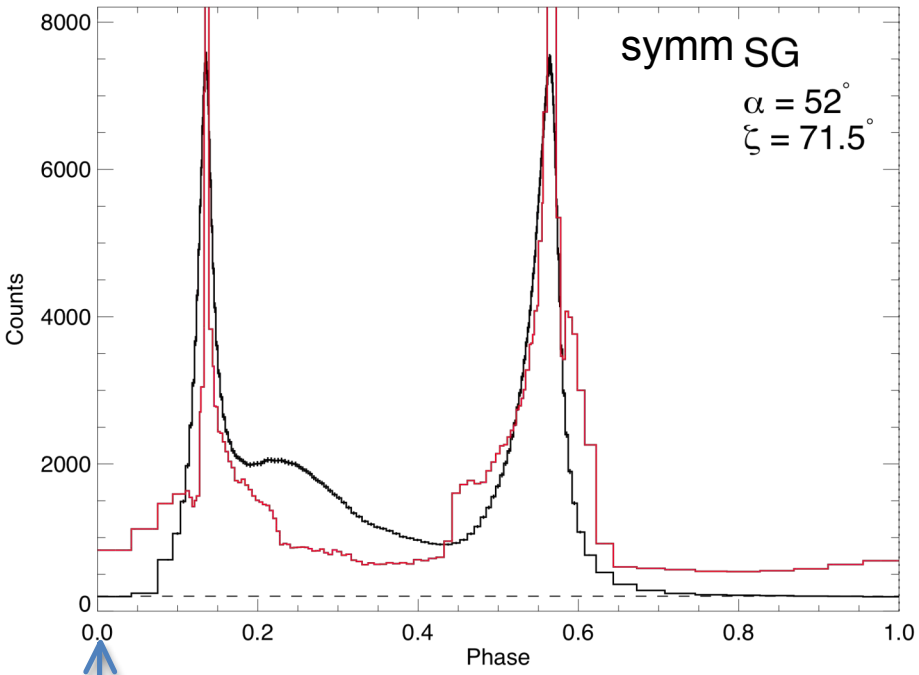
Gamma-ray/radio phase lag



Vacuum dipole model fits: Vela

preliminary

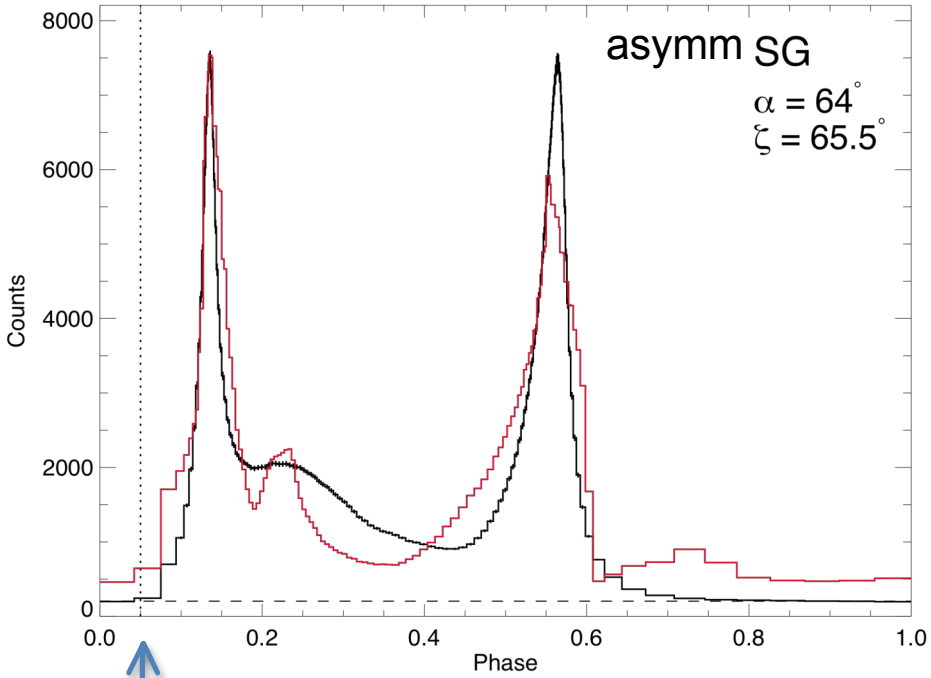
30 month survey data
4000 counts/bin



Magnetic pole

Vacuum, symm: $\chi_\nu^2 = 3298$
Vacuum, asymm: $\chi_\nu^2 = 1169$

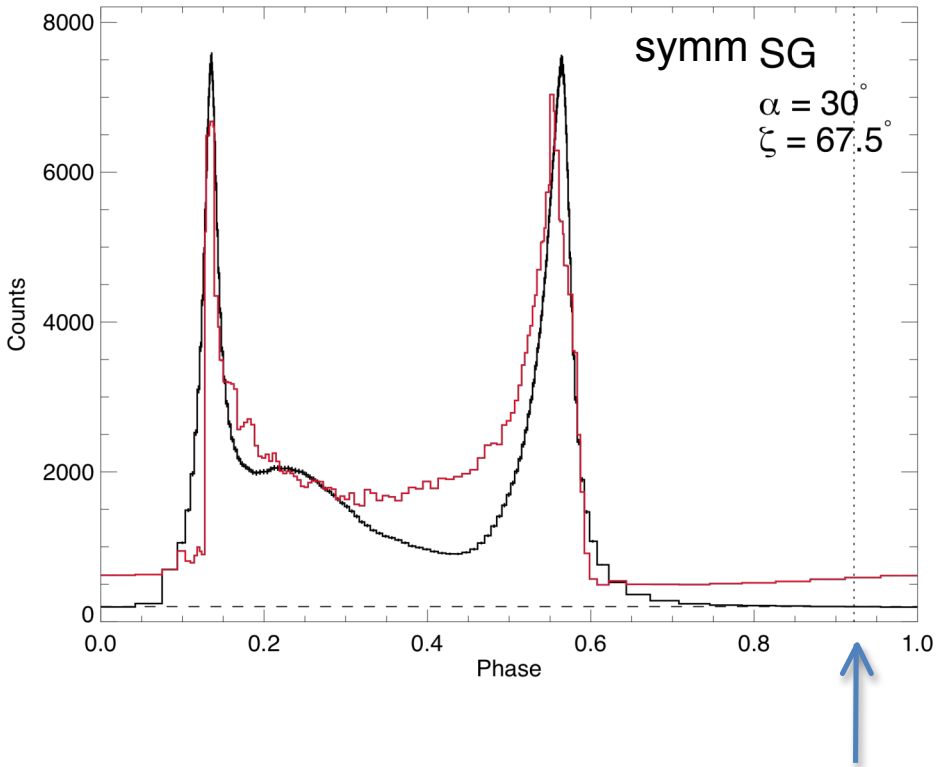
Markov Chain Monte Carlo method used to find maximum likelihood in $\alpha, \zeta, w, r_{max}$

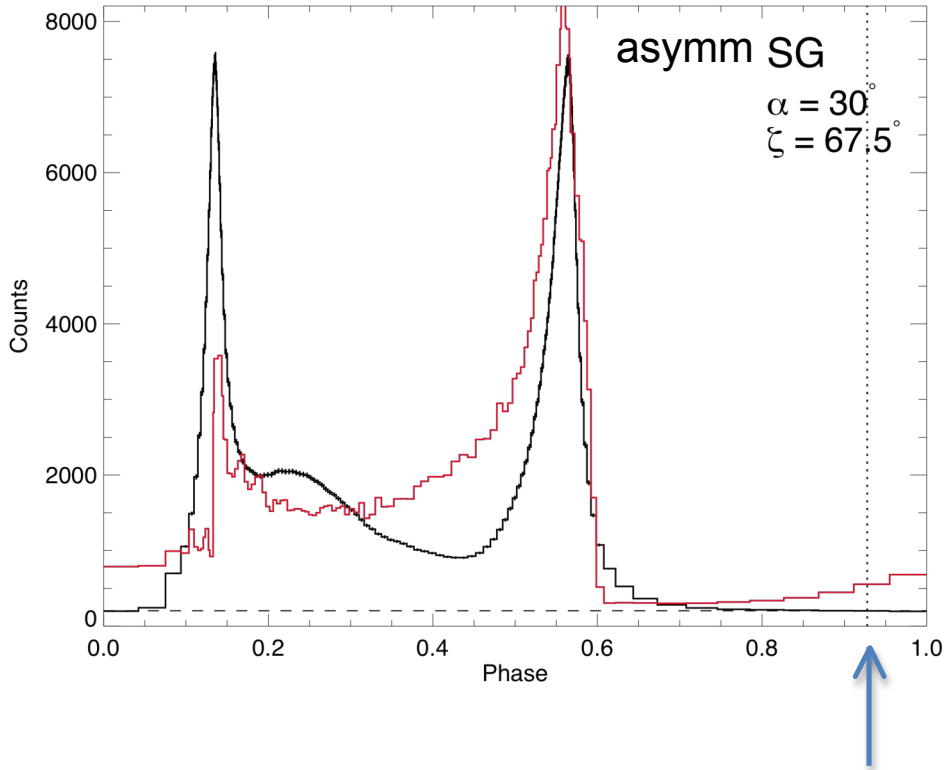


- Off-peak level lower with asymmetric $E_{||}$
- Better agreement with $\zeta = 64$ from X-ray torus (Ng & Romani 2009)

Force-free model fits: Vela

preliminary





Magnetic pole

FF, symm: : χ_ν^2 = 1145
FF, asymm: : χ_ν^2 = 1515

Off-pulse level lower in force-free geometry
MP lag too large for standard radio geometry
$\beta = \alpha - \zeta \sim 37^0$ – radio quiet pulsar?

Conclusions

- Vacuum slot gap LCs from asymmetric polar caps provide better fits to Vela – lower off-peak emission and agreement with ζ from X-ray torus

- Force-free model LCs fits comparable χ^2 to asymmetric vacuum dipole but
  - phase lag from magnetic pole too large (see also poster by DeCesar et al.)
  - $\alpha - \zeta \sim 37^0$ too large for radio-loud pulsar

- Radio phase lag will be an important diagnostic in finding "real" pulsar magnetosphere geometry (see poster by Kalapotharakos et al.)