Insights from Light Curve Modelling

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Pulsar Workshop, GSFC, USA , 6 - 8 June 2016

Thoughts on "The Scientific Method"

1. How do I Test a Pulsar Model?

2. How do we Test a Pulsar Model?

3. How do we Constrain a Pulsar Model?

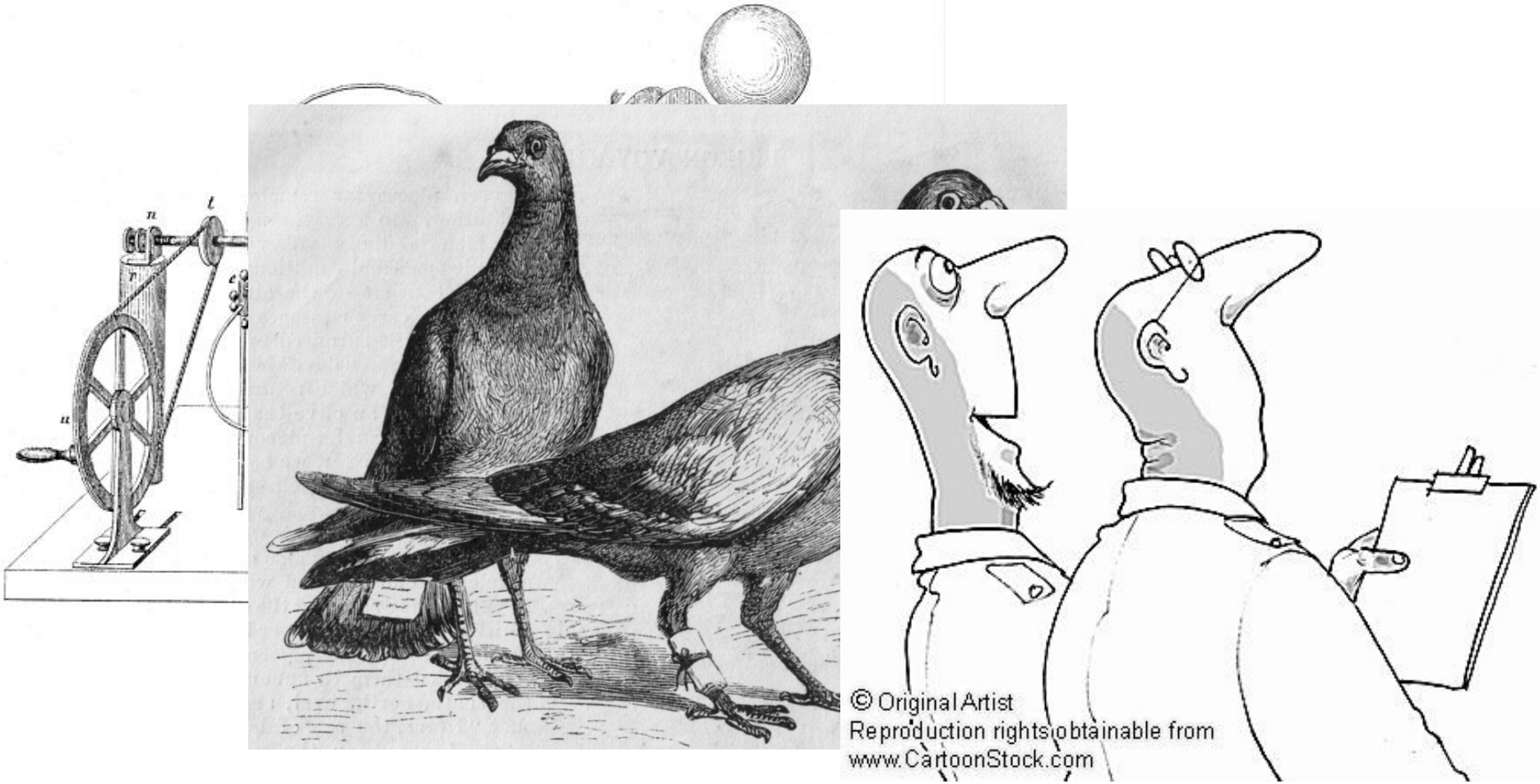
4. How do we Constrain Pulsar Models?

5. How do we Constrain Certain Aspects of Some Pulsar Models?

Testing / Constraining a Pulsar Model

By making detailed predictions…

And using all available data…



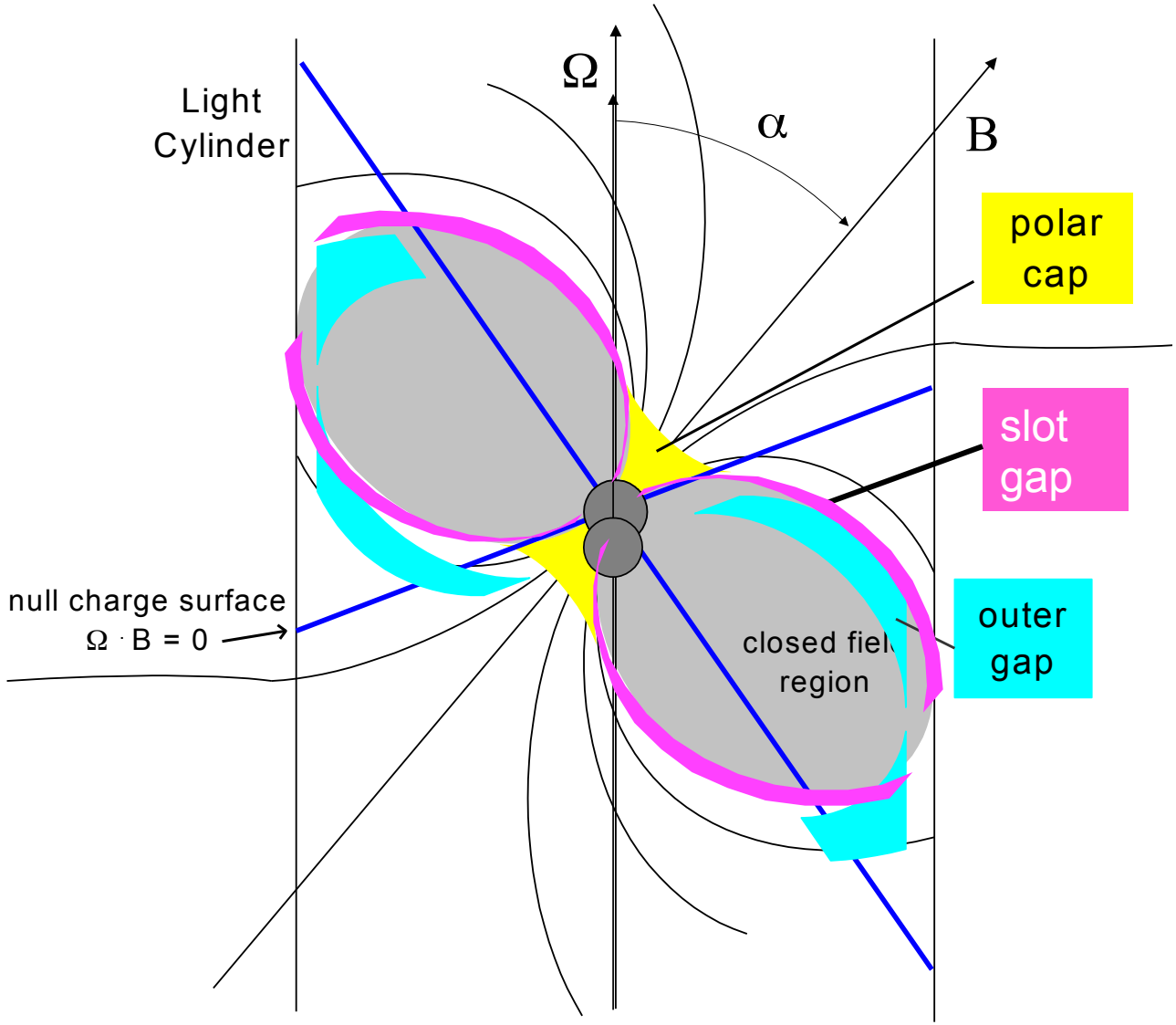
"System" **"Messengers"** **"Observables"**

Testing / Constraining a 'Pulsar' Model

"System"	"Messengers"	"Observables"
Isolated pulsars	Pulsed Photons	Light curves
Binary Pulsars	Unpulsed Photons	Spectra
PWNe	Particles	Polarization
Binary Pulsars	GWs	Variability
Globular Clusters	Neutrinos?	Spin-down
Pulsar Pop.		Morphology

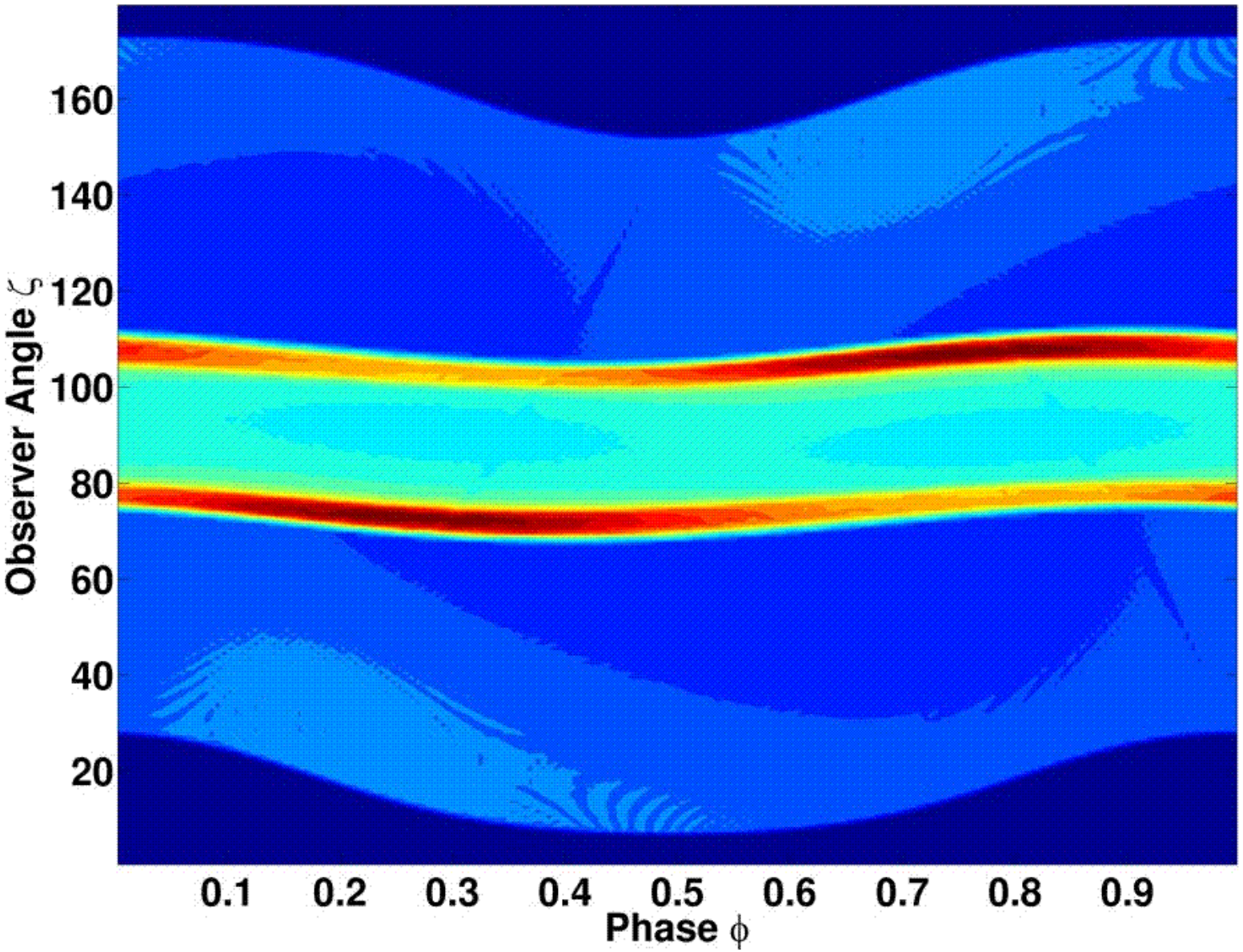
MODEL

Traditional Accelerator Geometries

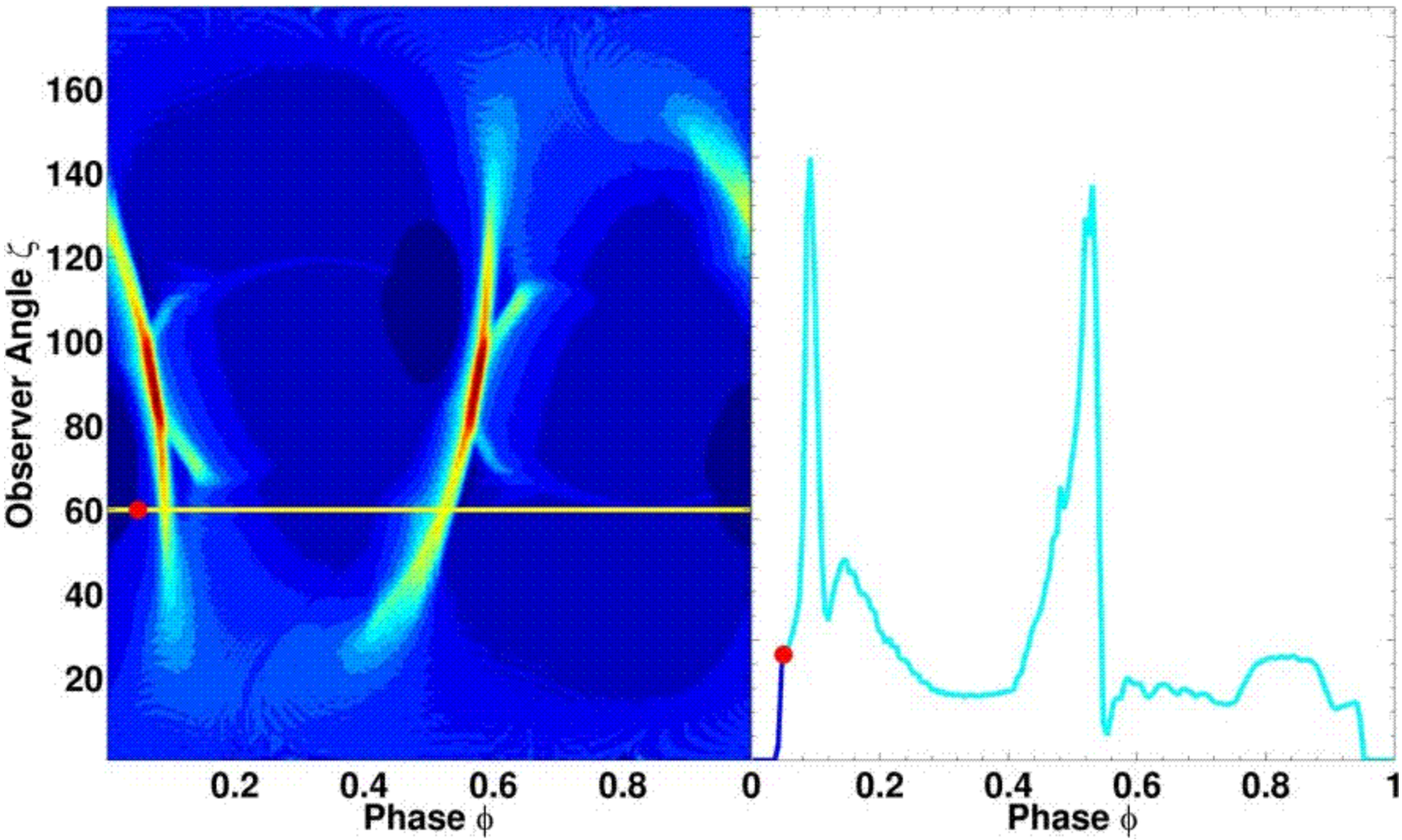


A. Harding

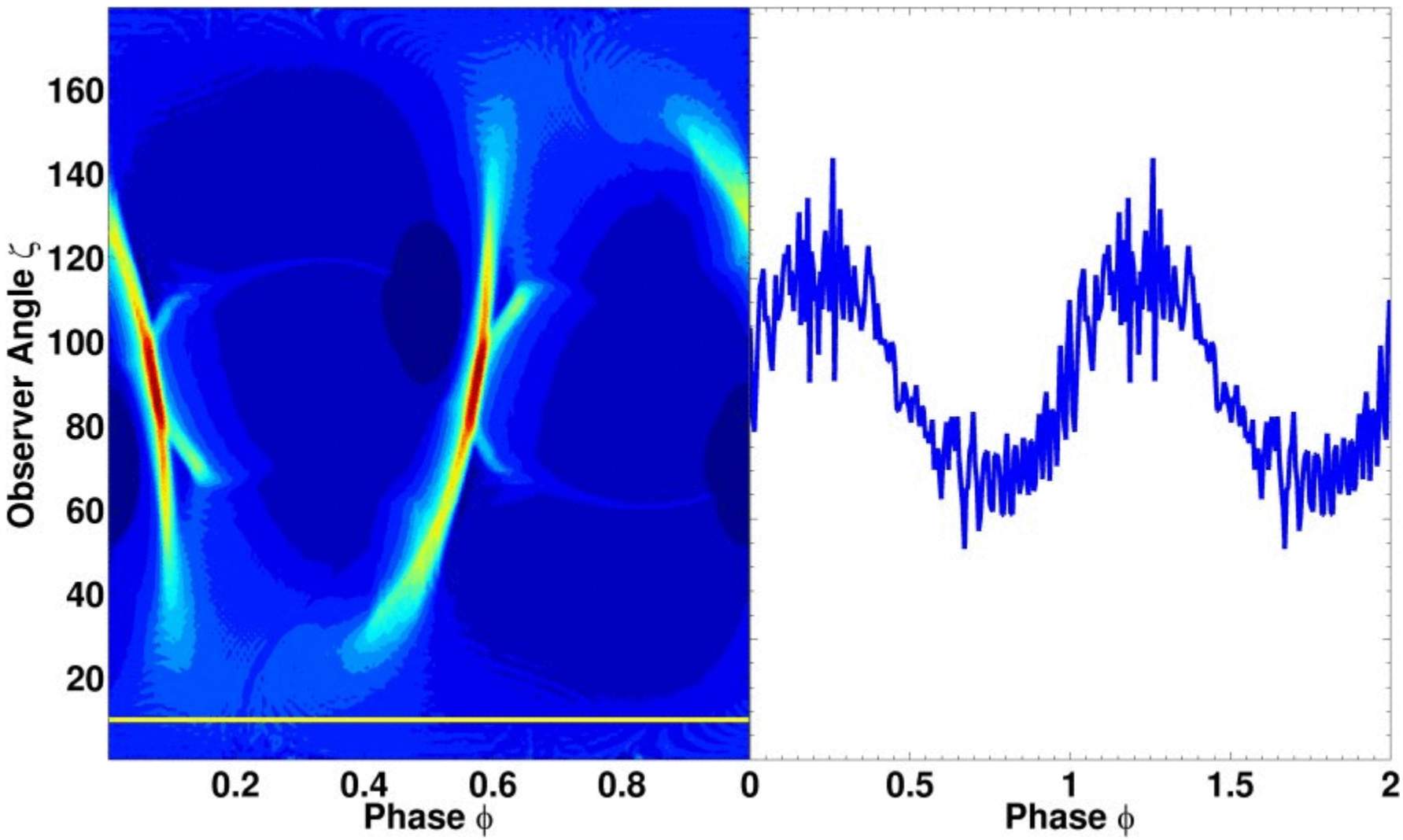
TPC Phaseplot as Function of α



Light Curve Calculation



Light Curves as Function of ζ



Radio Beam Geometry

Single-altitude conal radio beam

Harding et al. (2007); Gonthier (2004)

cf. Arzoumanian, Chernoff & Cordes (2002); Kijak & Gil (2003); Mitra & Deshpande (1999)

Total flux: $$S(\theta,\nu) = F_{\rm cone} e^{-(\theta-\bar{\theta})^2/\omega_e^2}$$

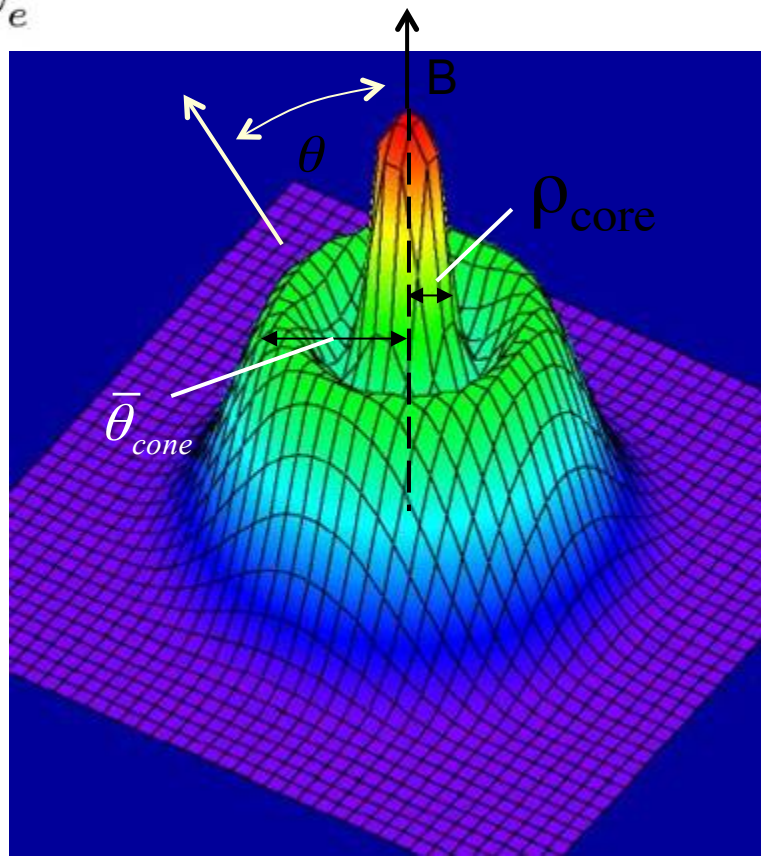
Cone radius: $$\rho_{\rm cone} = 1.24^\circ\, r_{\rm KG}^{0.5}\, P^{-0.5}$$

Cone position $$\bar{\theta} = (1.0 - 2.63\,\delta_w)\rho_{\rm cone}$$

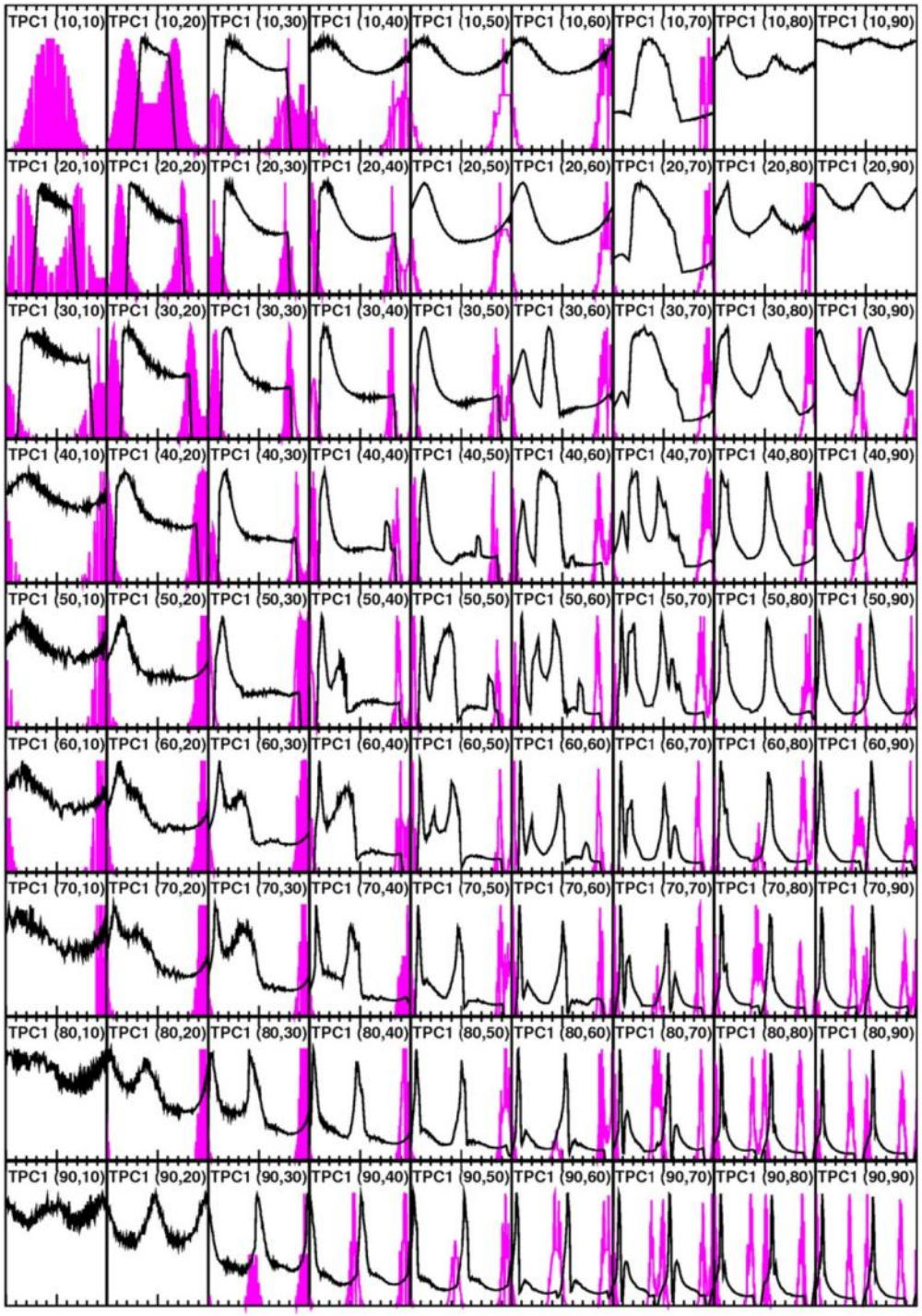
Cone width: $$w_e = \delta_w \rho_{\rm cone}$$

Emission altitude:

$$r_{\rm KG} \approx 40 \left(\frac{\dot{P}}{10^{-15}{\rm s\,s^{-1}}}\right)^{0.07} P^{0.3} \nu_{\rm GHz}^{-0.26}$$



Atlas of Light Curves (α,ζ)



Venter et al. (2009)

Radio

γ-ray

Major Conclusions

- Three broad classes for HE / radio LCs
- Copious pair production, even in MSPs
- Gamma rays from outer magnetosphere, radio from lower down (except for phase-aligned LCs)
- Important observables: Visibility, peak multiplicity, shape, off-peak emission, relative phase lag
- Beaming is important (efficiency or L_γ)
- Trends in 2PC provide further important tests
- Major shift in thinking: OG vs. TPC / SG to macro / microphysics questions

Venter & Harding (2014)

Some Open Questions

1. Rich variety of LCs: solely due to geometry, or distinct magnetospheric conditions and/or evolution effects?
2. No overall best-fit geometrical LC model: New / hybrid emission geometry?
3. Will preliminary trends strengthen? Do we need noncanonical pulsar parameters?
4. Preferred magnetospheric structure? Reconnection?
5. Origin of pulsed TeV photons?

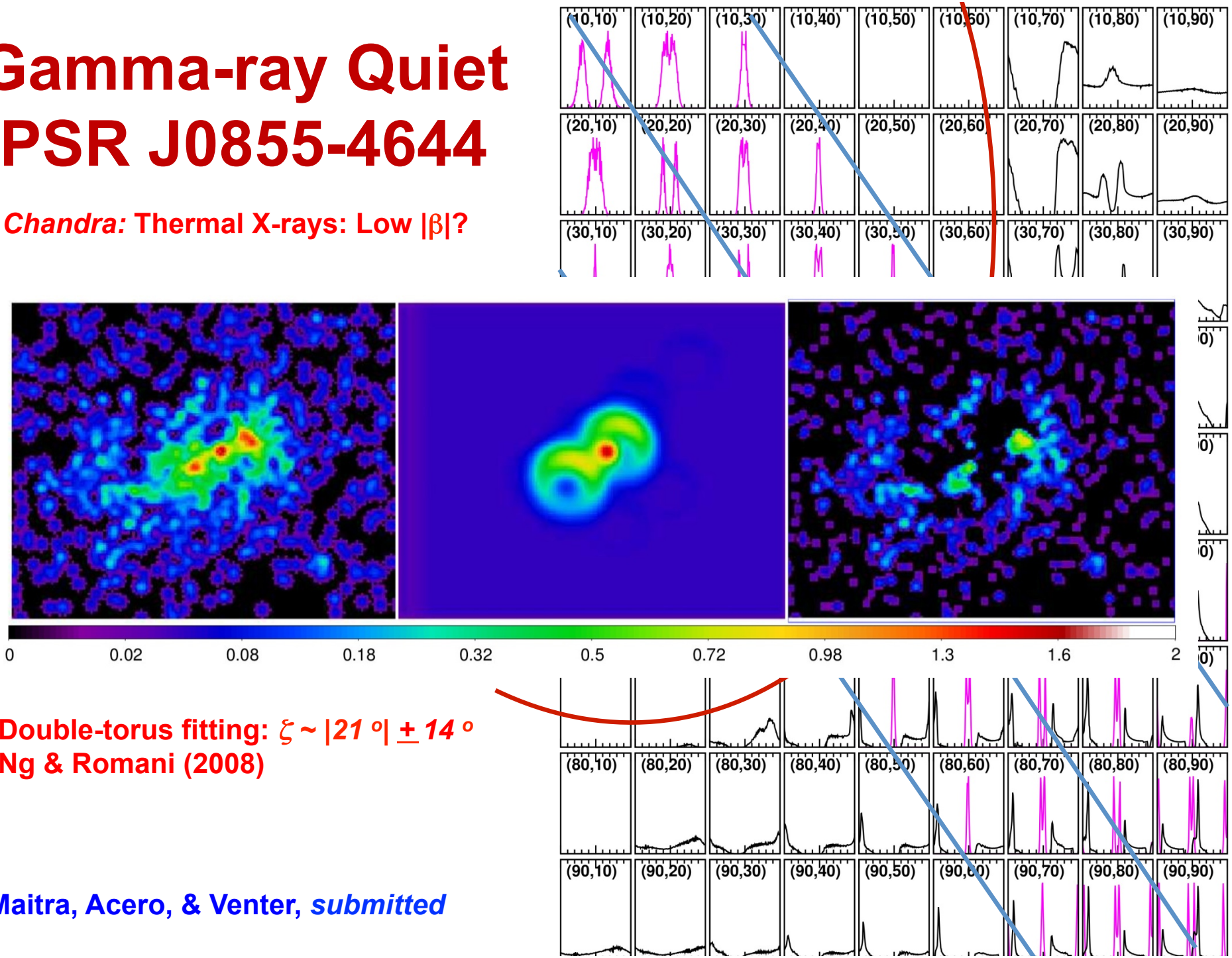
Venter & Harding (2014)

Refinements / New Directions

1. **Multiwavelength constraints: pulsar geometry**
2. **Towards rigorous multiband LC fits**
3. **Effect of *B*-field and *E*-field on LC**
4. **“All roads lead to the current sheet”**

Gamma-ray Quiet PSR J0855-4644

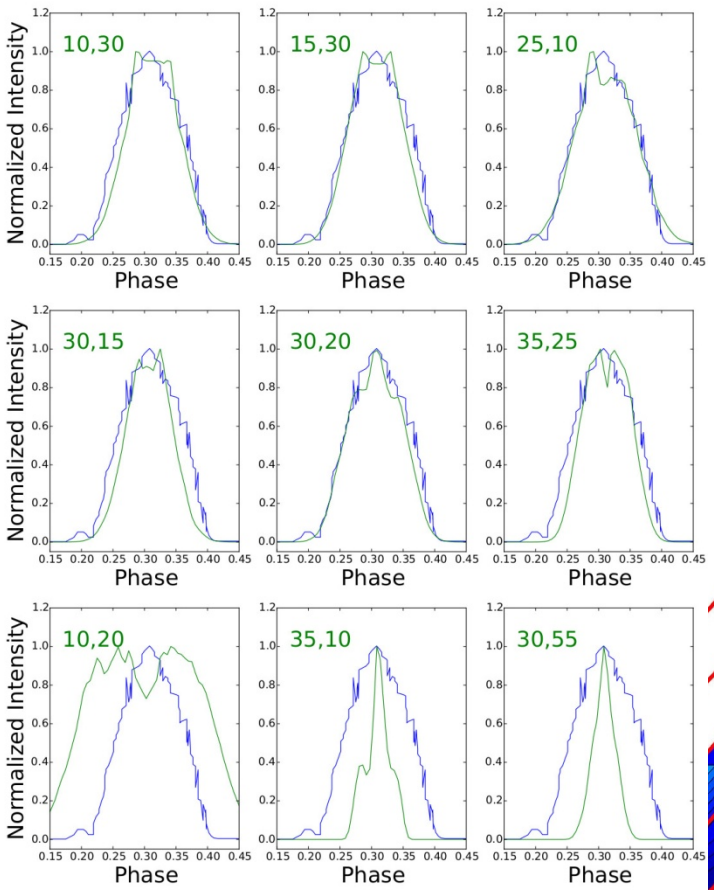
Chandra: **Thermal X-rays: Low |β|?**

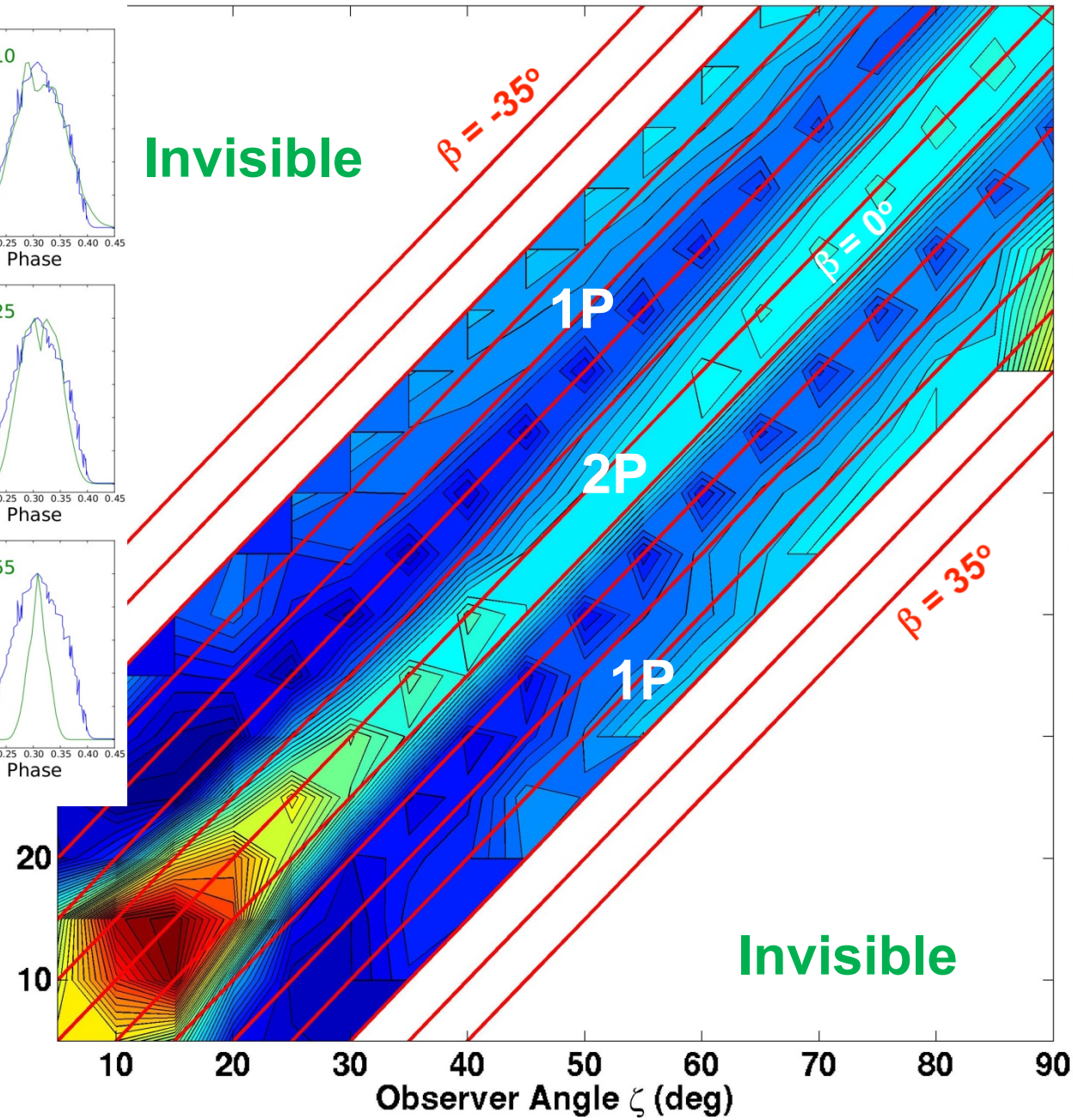


Double-torus fitting: $\zeta \sim |21^{o}| \pm 14^{o}$
Ng & Romani (2008)

Maitra, Acero, & Venter, *submitted*

Radio Peak: Visibility, Multiplicity, Width

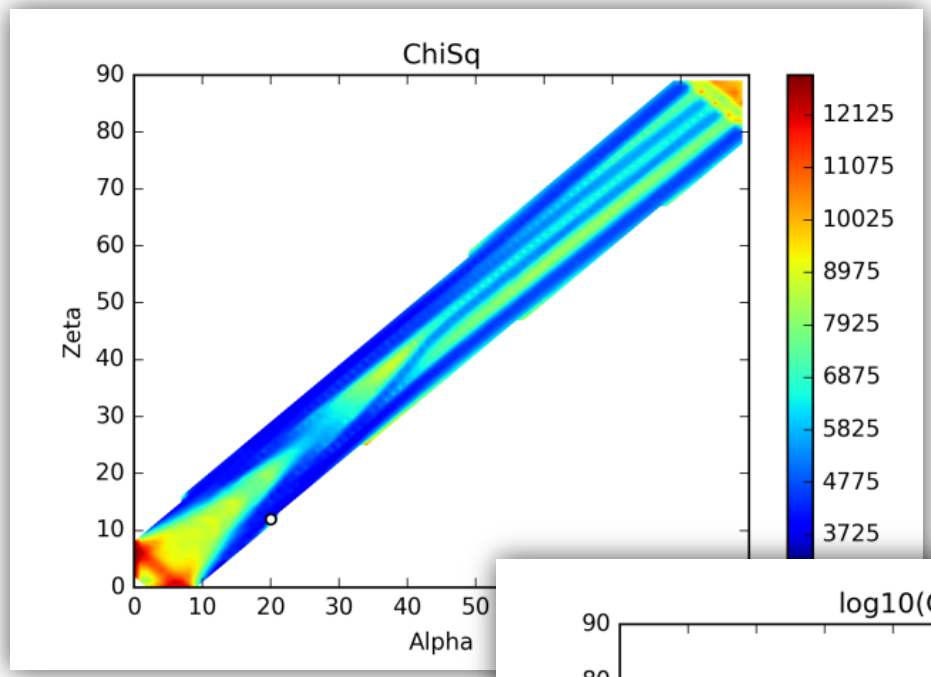


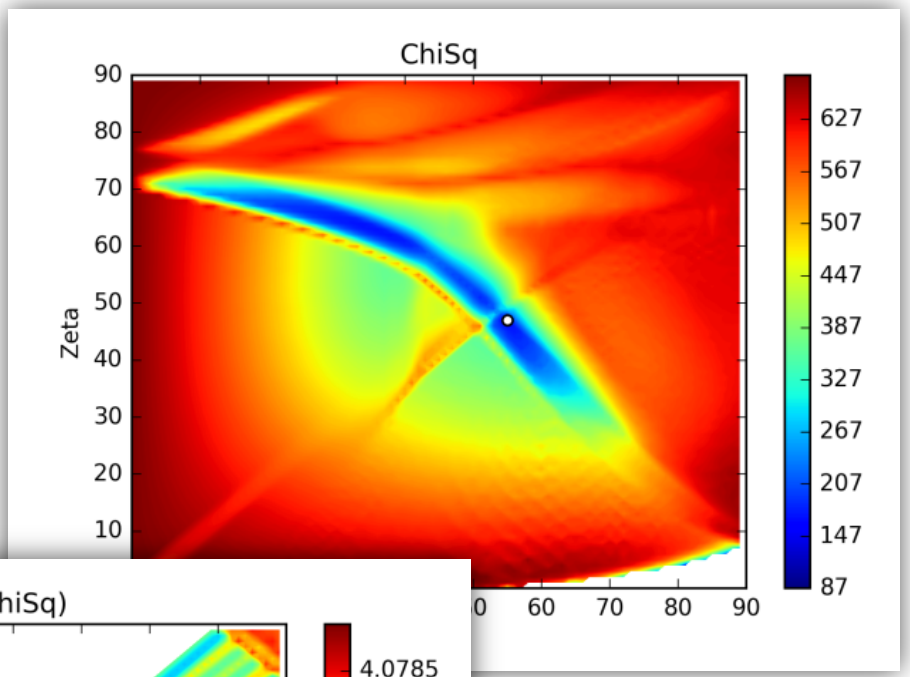


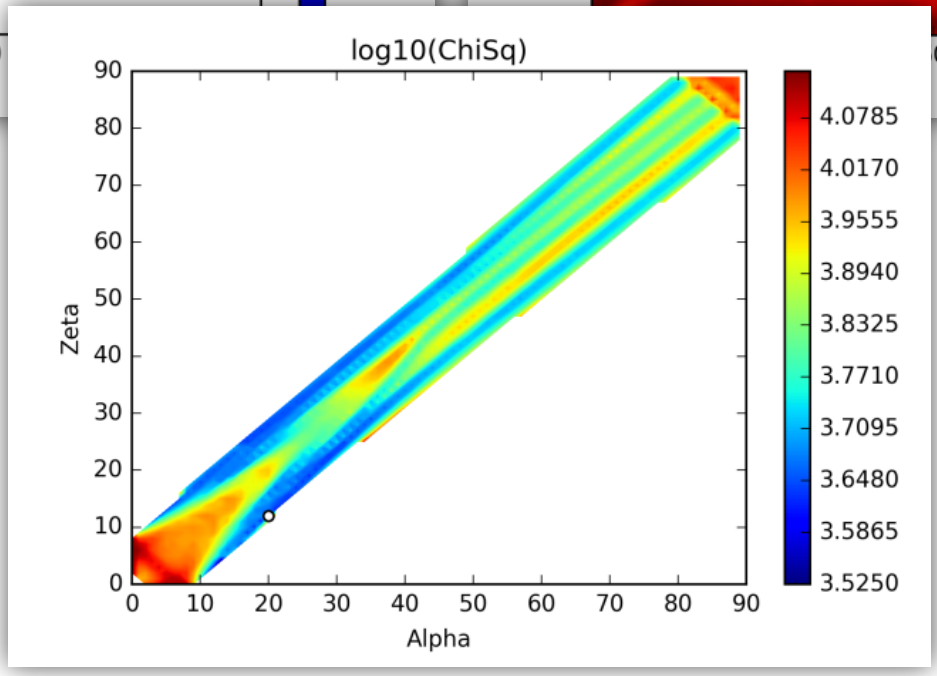
$\alpha < 40°$; $\zeta \sim < 40°$
$10° < |\beta| < 25°$

Maitra, Acero, & Venter, *submitted*

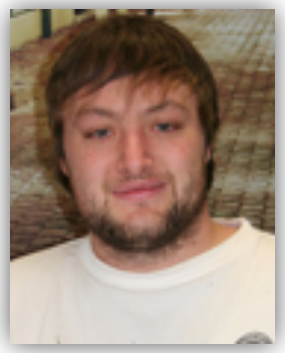
2. Rigorous Best-Fit Method







Seyffert, Venter, & Harding ,
in prep.



3. Effect of *B*-field geometry / *E*-field

→ **Static dipole *B*-field (Griffiths 1995)**

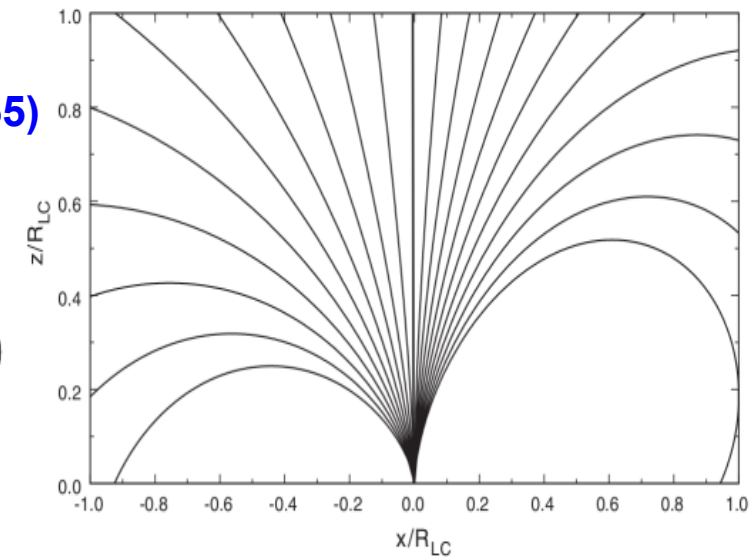
$$B_{\mathrm{st,r}} = \frac{2\mu}{r^3}\cos\theta \qquad B_{\mathrm{st},\theta} = \frac{\mu}{r^3}\sin\theta.$$

→ **Retarded vacuum dipole (RVD) (Deutsch 1955)**

$$B_{\mathrm{ret,r}} = \frac{2\mu}{r^3}[\cos\alpha\cos\theta + \sin\alpha\sin\theta(r_{\mathrm{n}}\sin\lambda + \cos\lambda)]$$

$$B_{\mathrm{ret},\theta} = \frac{\mu}{r^3}(\cos\alpha\sin\theta + \sin\alpha\cos\theta[-r_{\mathrm{n}}\sin\lambda + (r_{\mathrm{n}}^2 - 1)\cos\lambda])$$

$$B_{\mathrm{ret},\phi} = -\frac{\mu}{r^3}\sin\alpha[(r_{\mathrm{n}}^2 - 1)\sin\lambda + r_{\mathrm{n}}\cos\lambda]$$



→ **Offset-PC field characterized by parameters ε and ϕ_0 (magnetic azimuthal angle) (Harding & Muslimov 2011)**

$$\mathbf{B}'(r',\theta',\phi') = \frac{\mu}{r'^3}\left[\cos\theta'\hat{\mathbf{r}}' + \frac{1}{2}(1+a)\sin\theta'\hat{\boldsymbol{\theta}}' - \epsilon\sin\theta'\cos\theta'\sin(\phi'-\phi_0)\hat{\boldsymbol{\Phi}}'\right]$$

$$a = \epsilon\cos(\phi' - \phi_0)$$

Barnard, Venter, & Harding , *submitted*

Conclusions

1. *Geometric LC models have taught us a lot about the emission region's location and geometry*
2. *We need to keep refining and expanding them, since they may inform the physical models on geometrical aspects*
3. *We need to move to full emission models*
4. *"Ground" physical models in (e.g., LC / spectral) data*

"Love never fails…" (1 Cor. 13:8 NKJV).

This work is based on the research supported wholly / in part by the National Research Foundation of South Africa (Unique Grant Number 92860, 2014)

NRF National Research Foundation | RISA Research and Innovation Support and Advancement