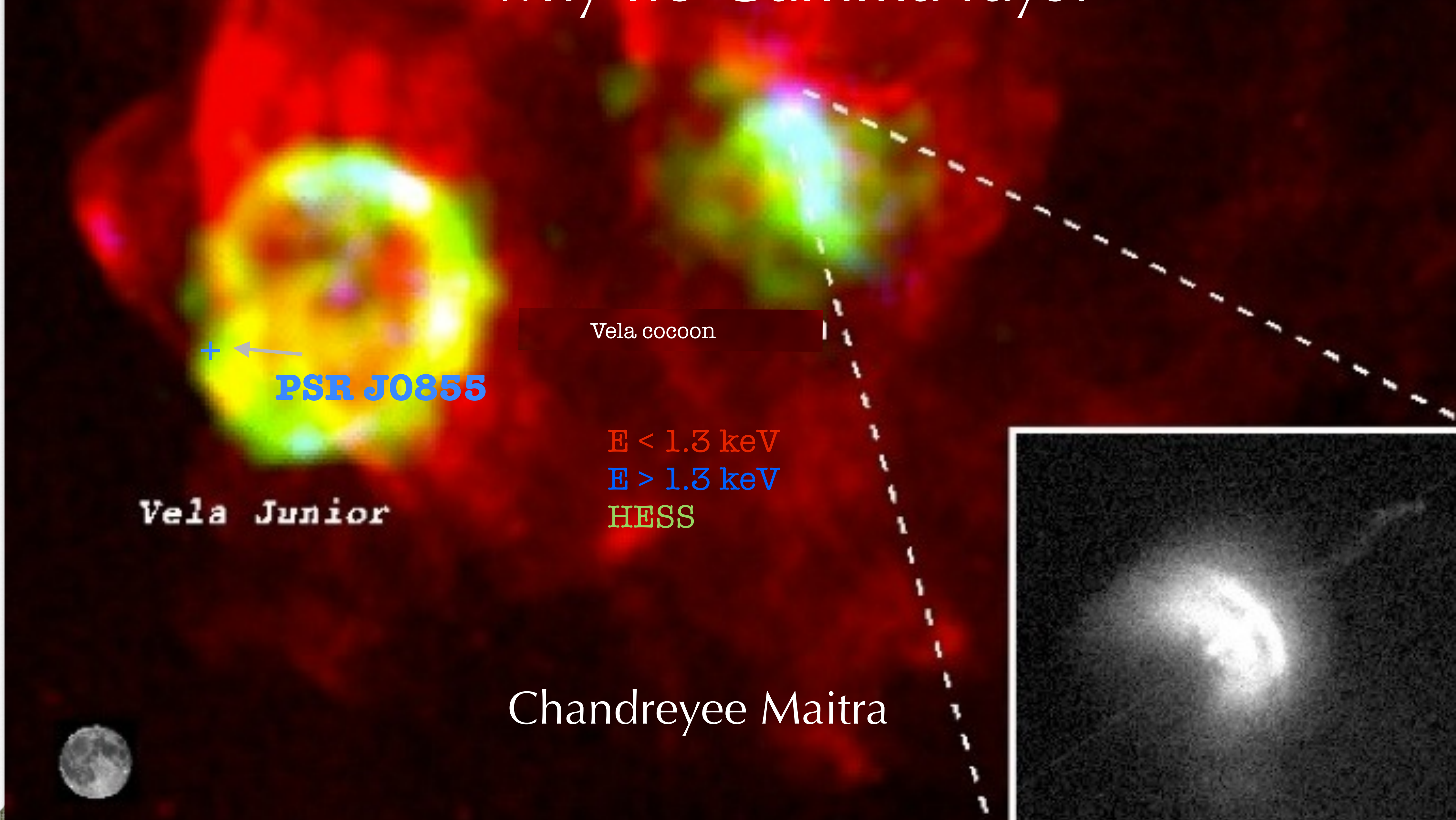
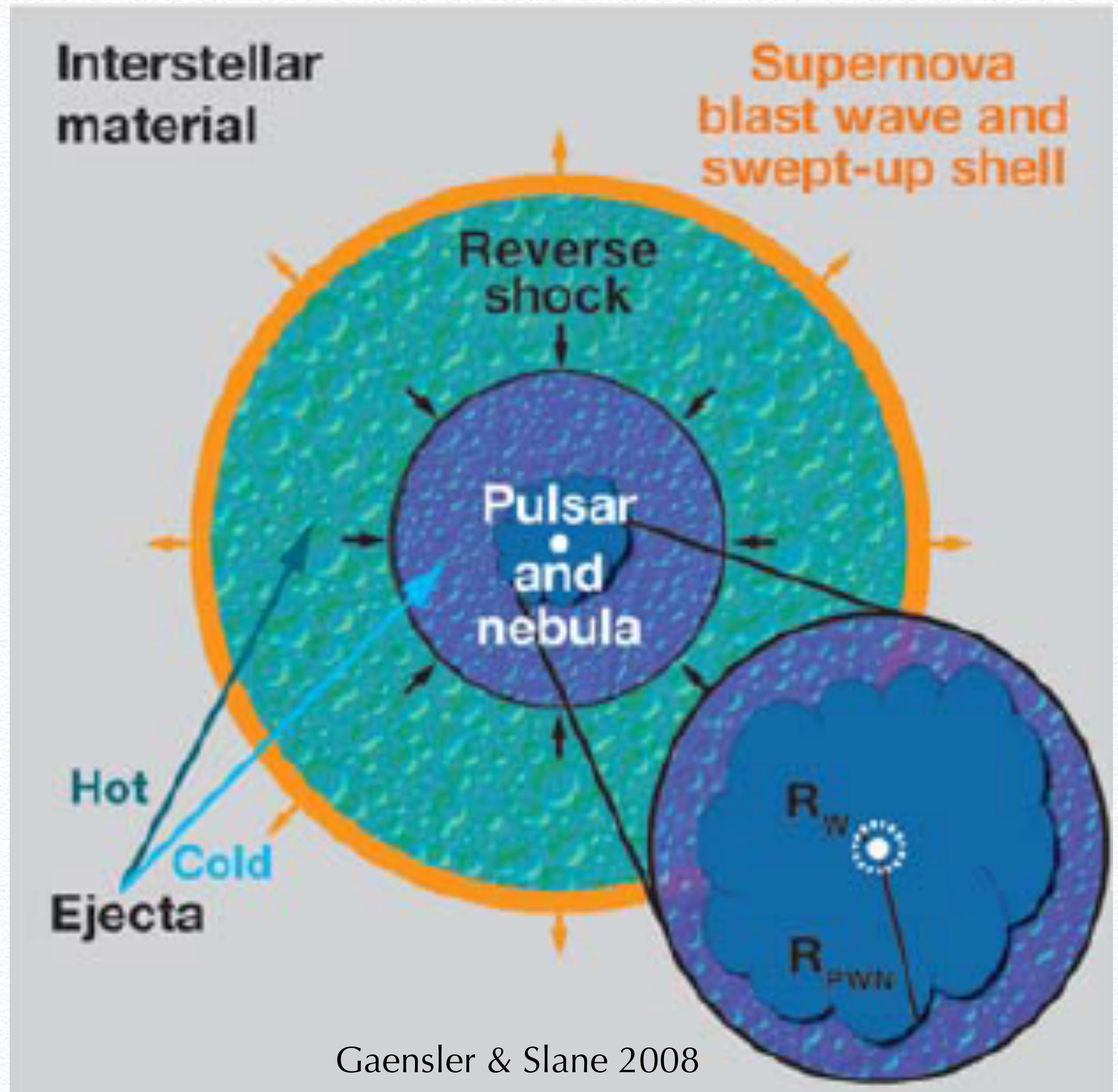
Max-Planck-Institut für
extraterrestrische Physik

Unveiling the intriguing nature of PSR J0855-4644: why no Gamma rays?



Chandreyee Maitra

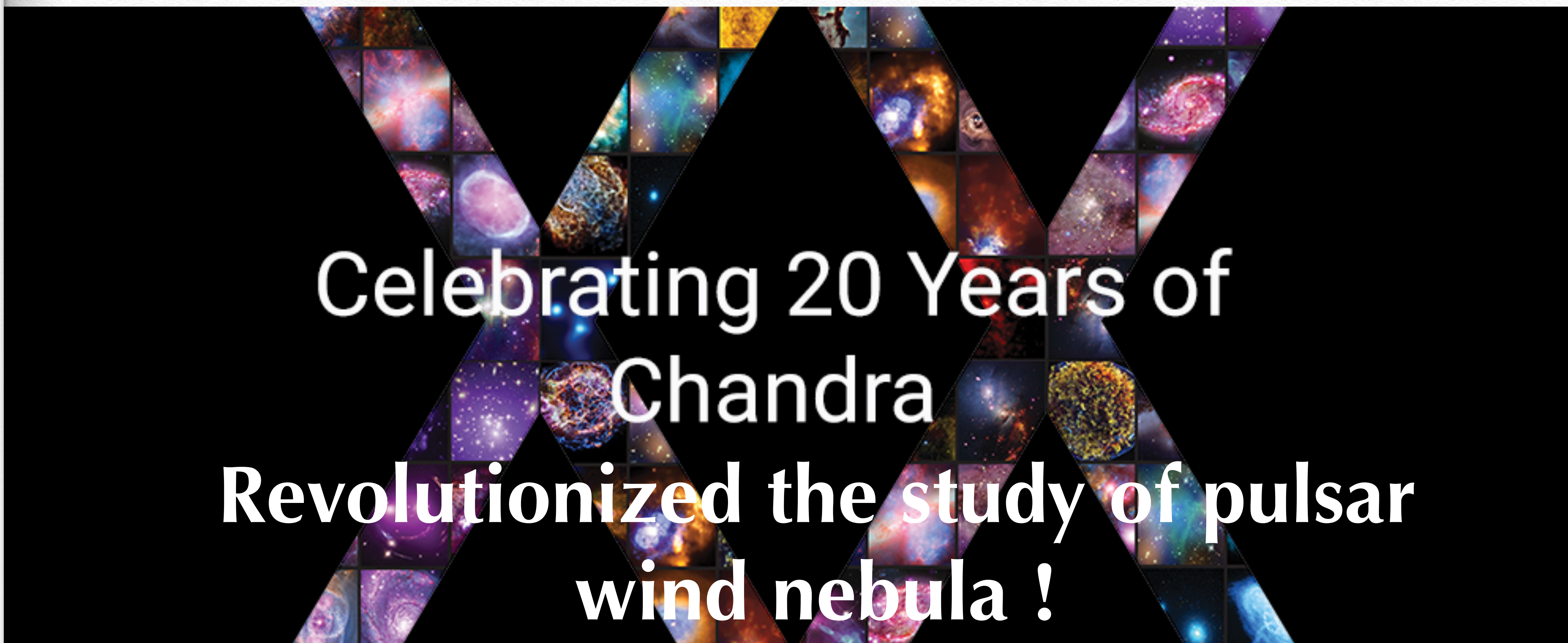
a) **Anisotropic wind structures** (tori/jet)
b) **Bow shocks**
c) **Anisotropies**



Gaensler & Slane 2008

Resolved sub arc second structures of the PWNe:

a) **Anisotropic wind structures** (tori/jet)
b) **Bow shocks**
c) **Anisotropies**



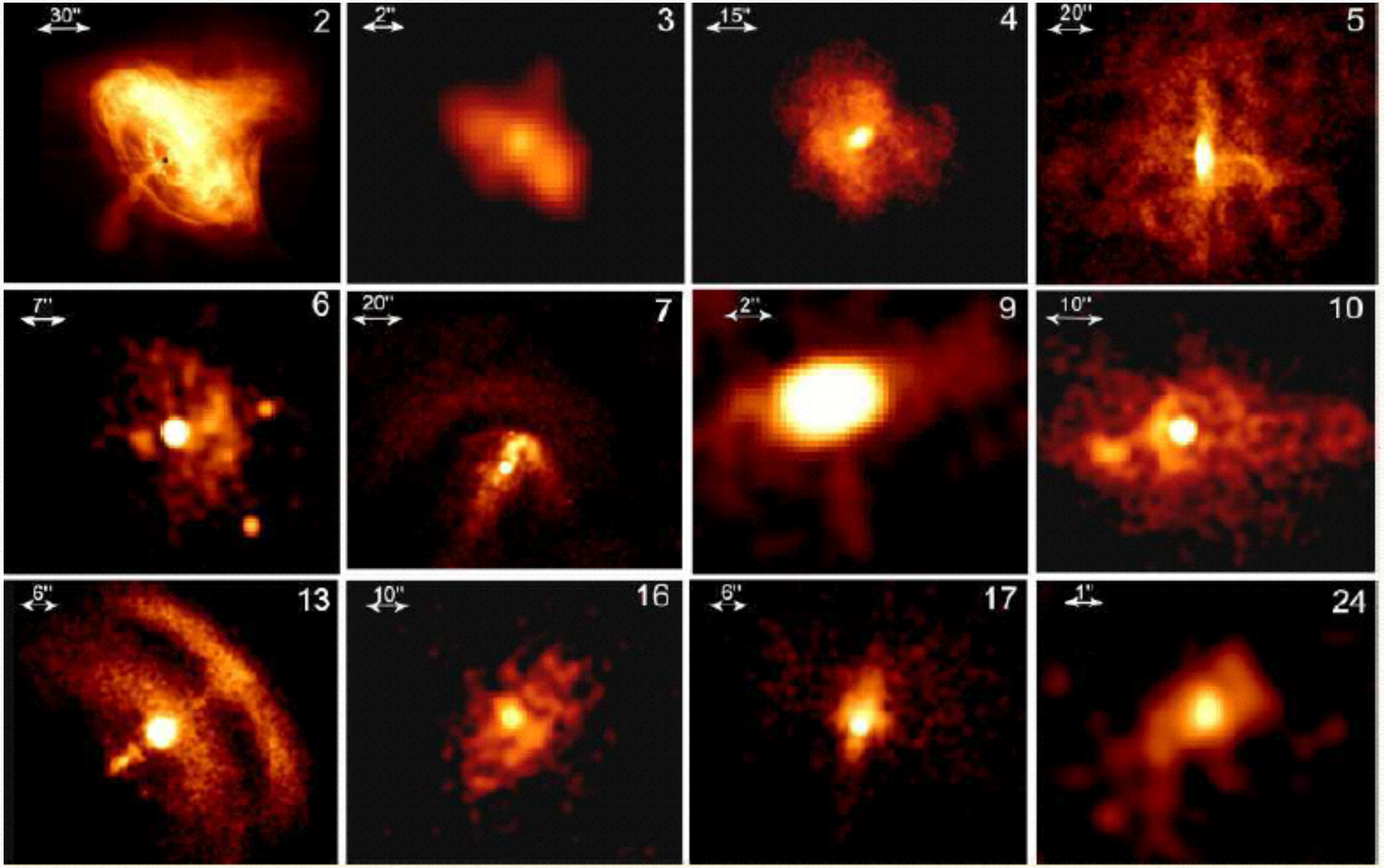
Revolutionized the study of pulsar wind nebula !

Resolved sub arc second structures of the PWNe:

a) **Anisotropic wind structures** (tori/jet)

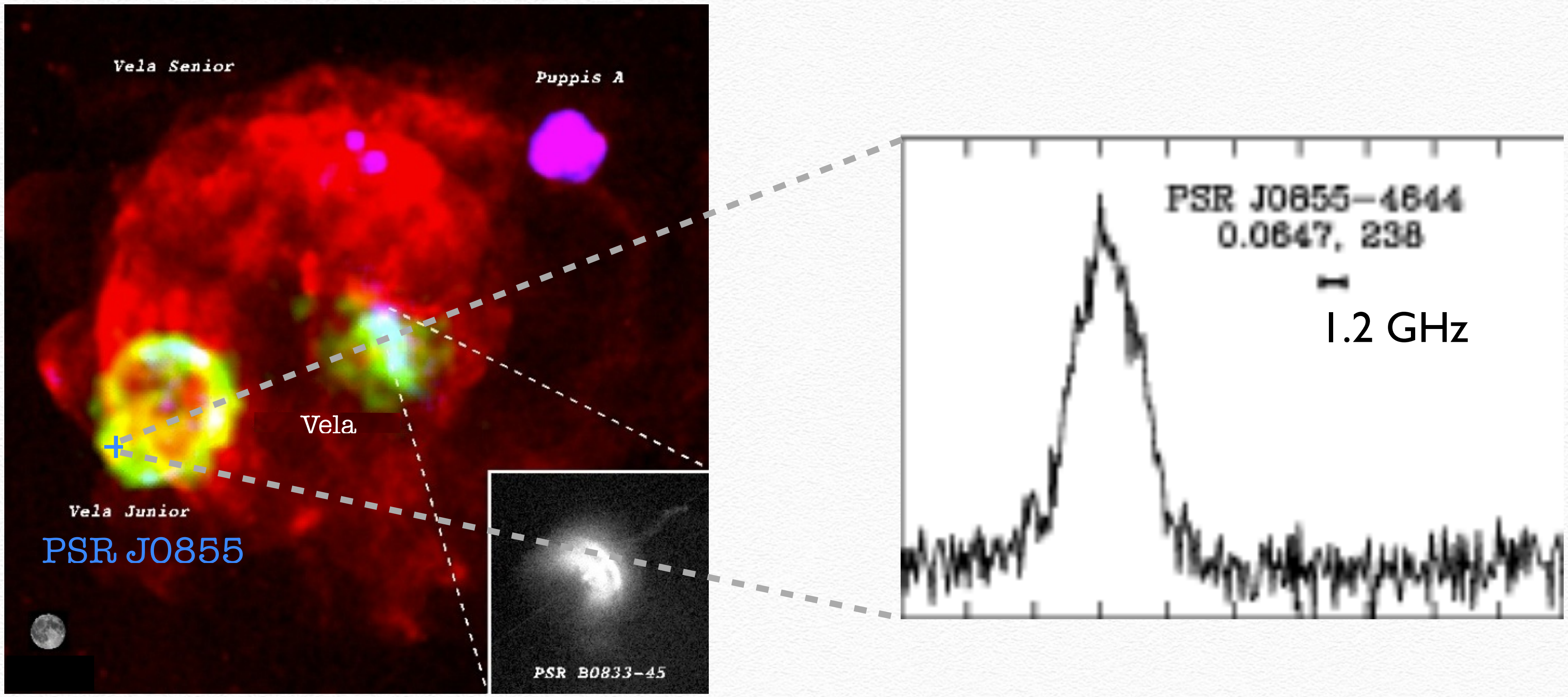
b) **Bow shocks**

PWNe ZOO



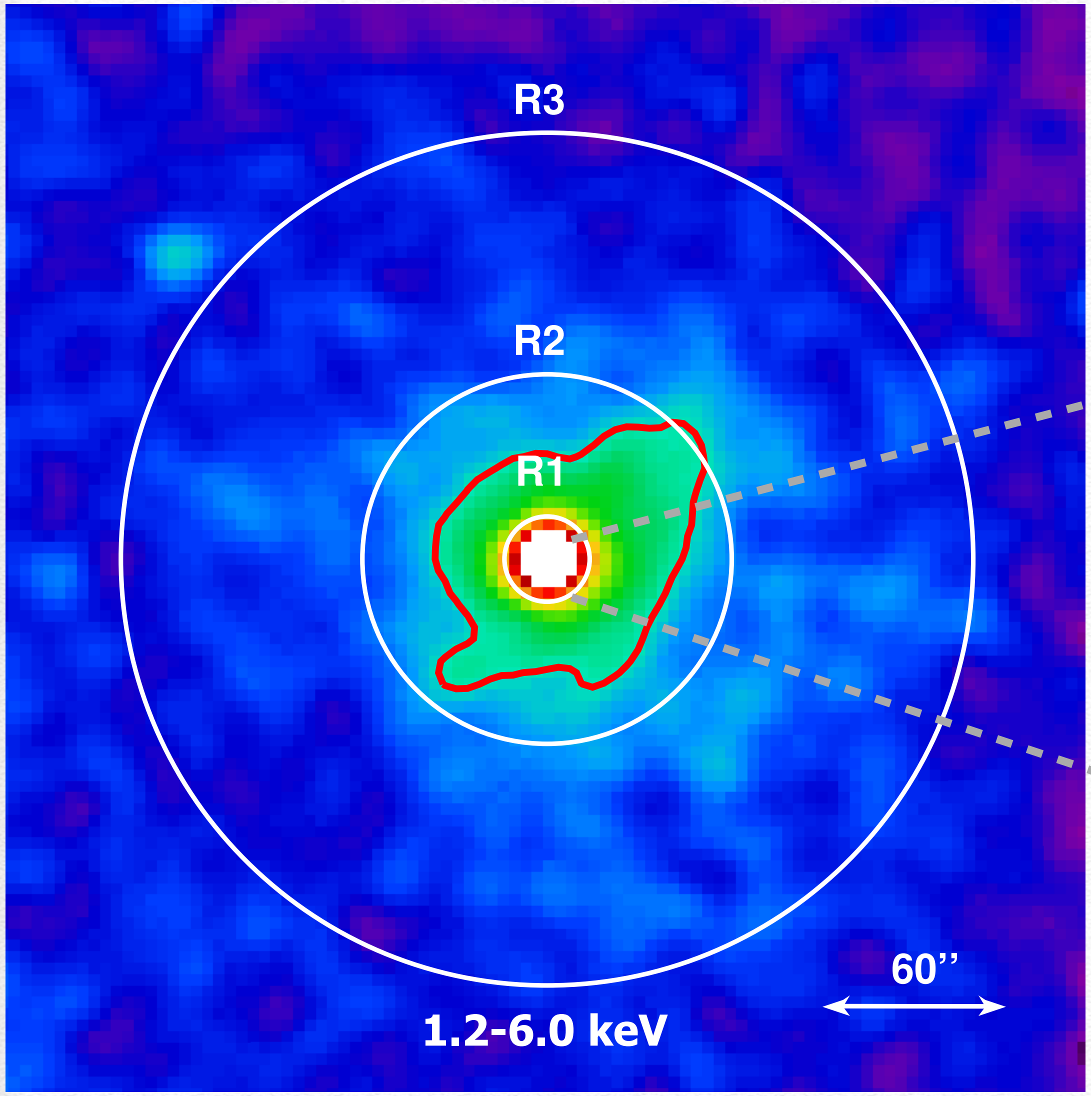
Pavlov & Kargalstev 2006

PSR J0855-4644: nearby fast spinning, energetic radio pulsar



- Fast pulsar P = 65 ms, $\dot{P}$=7.26 *10^{-15} $\dot{E}$ =1.1 *10^{36} erg/s (from Parkes radio survey)
- Distance < 1 Kpc (X-ray Nh estimate) ; second most energetic pulsar after Vela at this distance
- **Highest $\dot{E}/d^2$ system not seen by Fermi**

Through the eyes of XMM-Newton

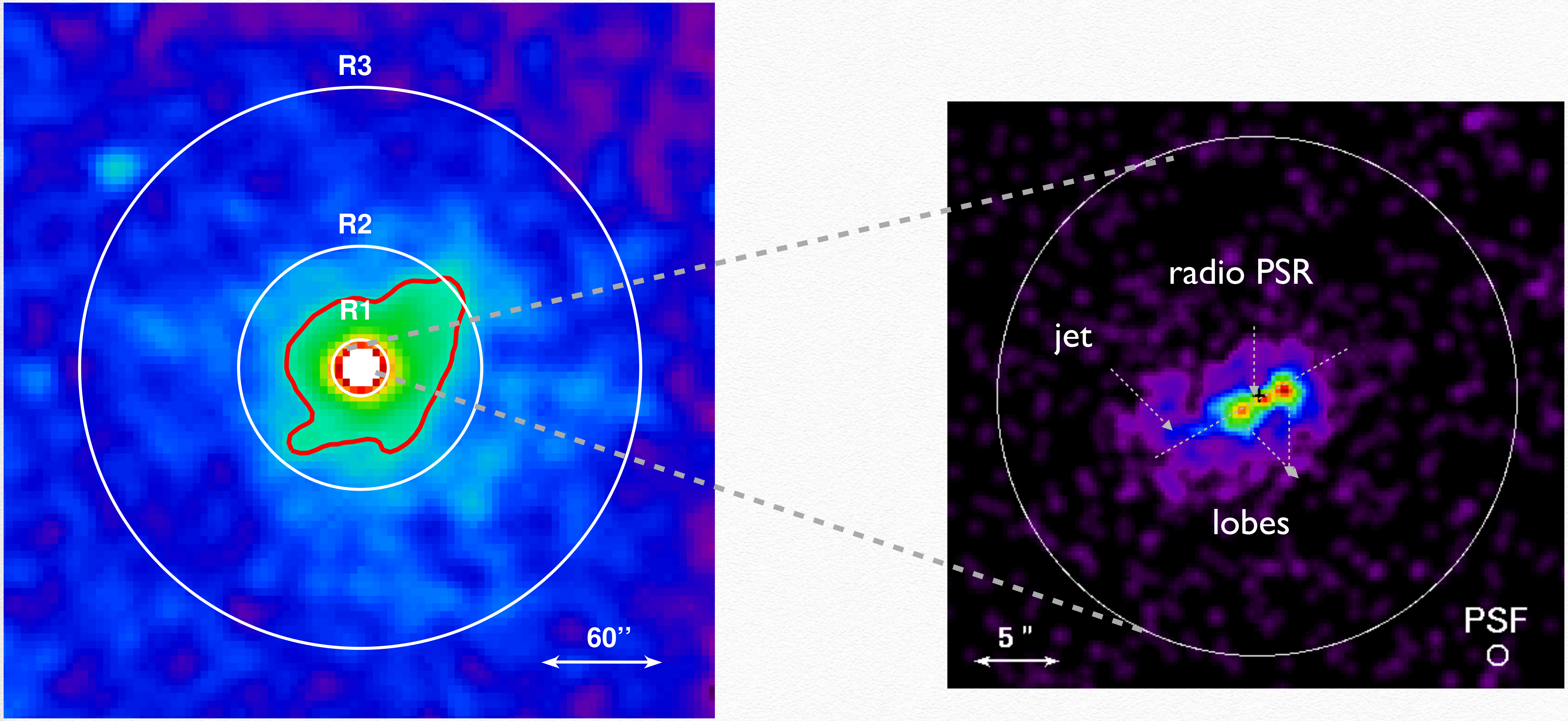


R1=15''

X-ray counterpart of pulsar
?

PWN revealed ~150 " in extent
Acero et al. 2013, A&A, 551, A7

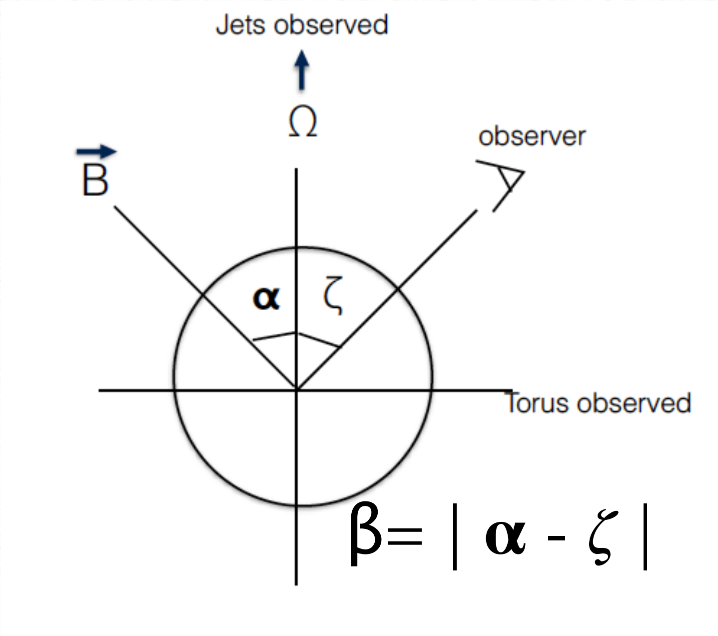
Through the eyes of Chandra: Structured PWN revealed!

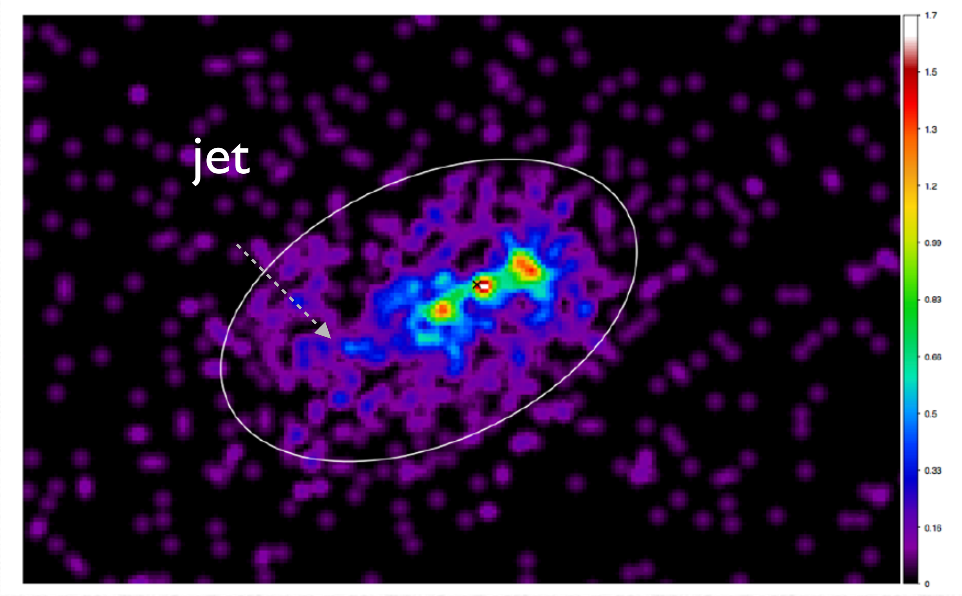


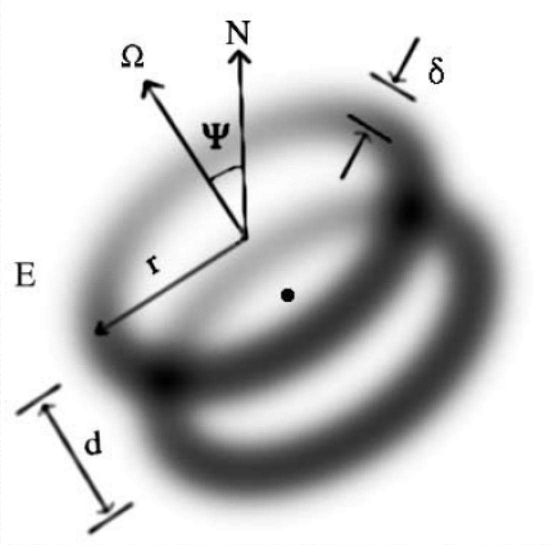
<u>Chandra: 38 ks ACIS-S observation</u>

- What was thought to be X-ray pulsar: further resolved to 10″ compact PWN (0.06 pc)
- Two lobes symmetric about the pulsar → jets OR double torus+one sided jet
- Very faint pulsar; contributes to 1% of flux of the XMM compact source, no non-thermal emission

Spatial modeling: torus & jet structures indicate **spin inclination** of the pulsar

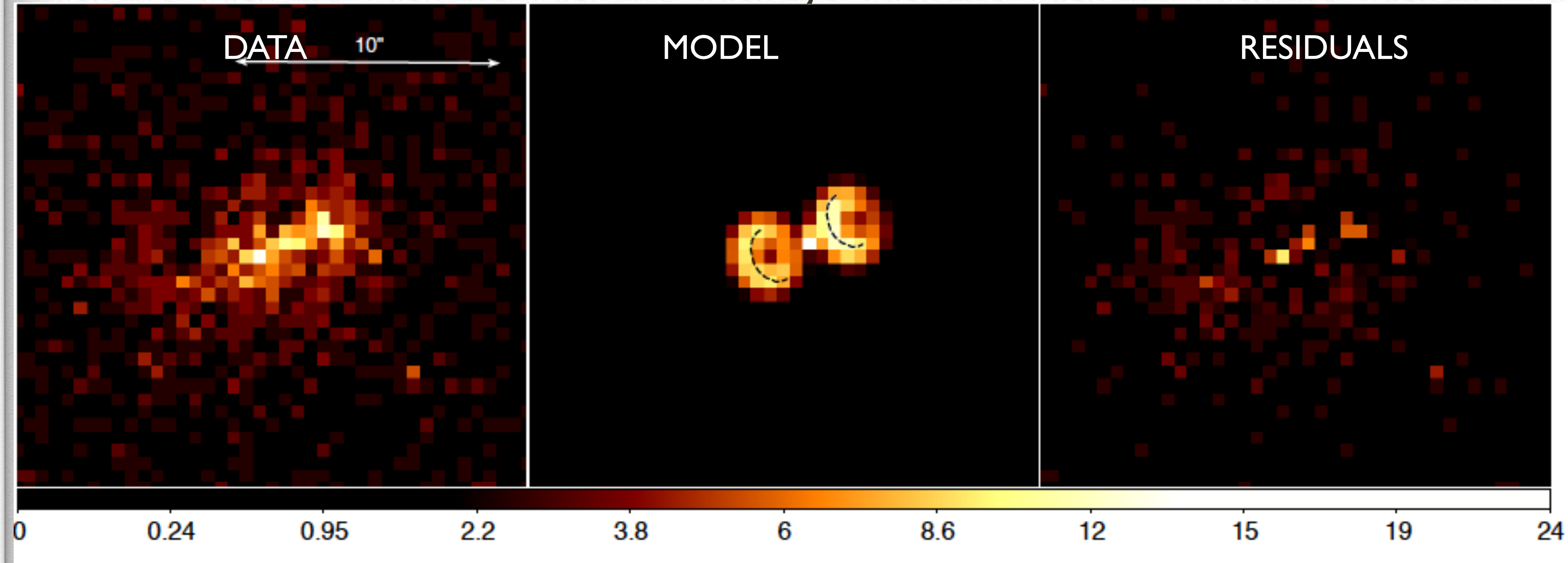




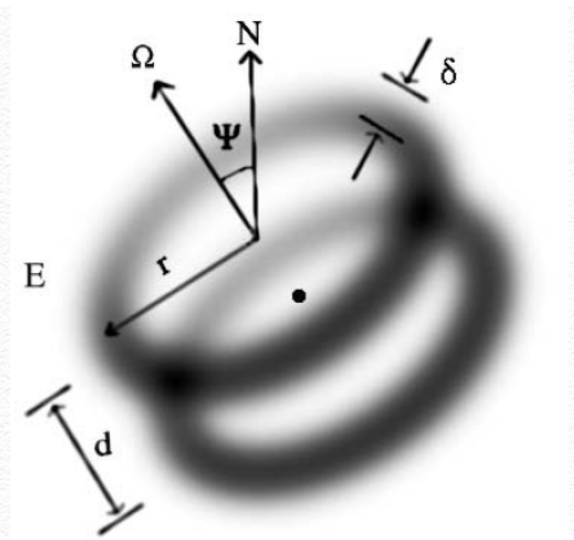


- Parameters PA Ψ (N to E), spin inclination ζ , torus radius (r), postshock velocity β (Ng & Romani 2004)

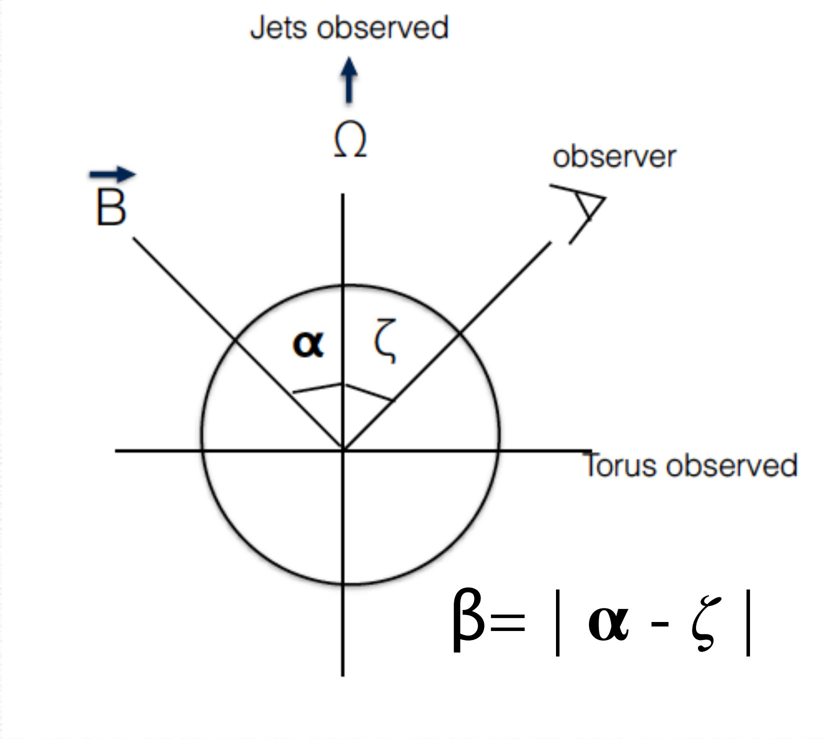
Spatial modeling: Can we answer why no Gamma ray emission?



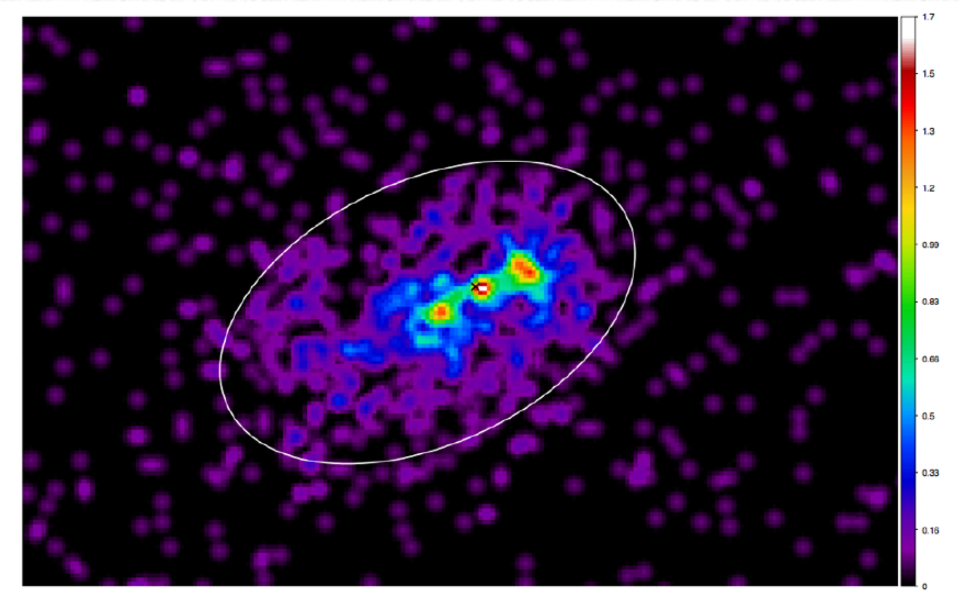
Parameter	Value
position angle Ψ	114.4±2.3±1.1±
spin inclination ζ	32.5±4.0°±1.7°
radius of each torus R	2.1±0.06±0.08°
post-shock flow velocity β	0.41±0.06±0.06
seperation between each torii d	3.6±0.70±0.30



Geometry of PSR J0855-4644: radio loud, γ ray quiet with high $\dot{E}/d^2$

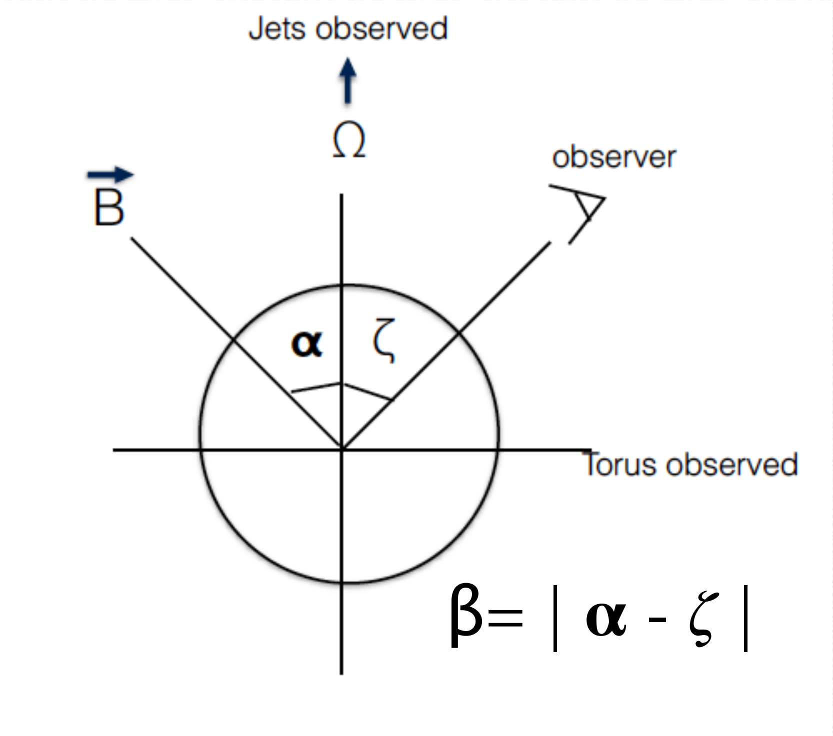


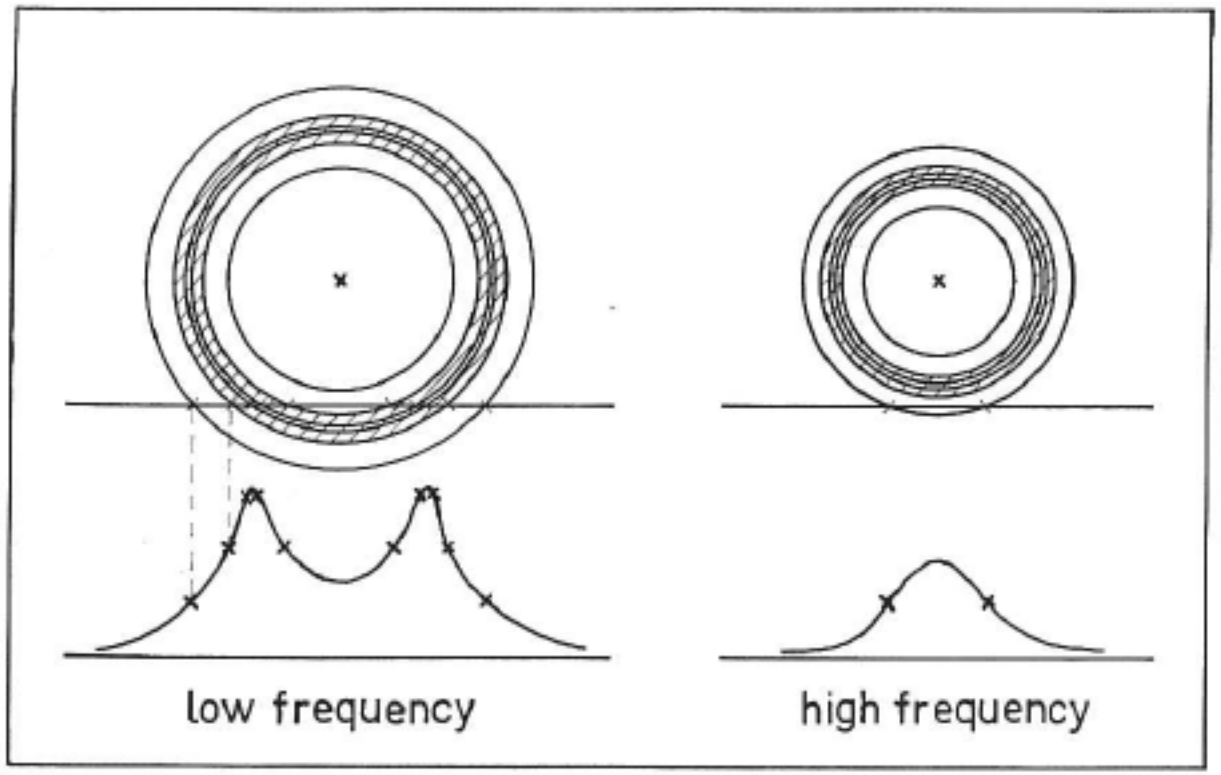
- Double torus fit to the PWN implies $\zeta < 37°$
- Small viewing angles limits access to X-ray/ gamma ray beam ?
- Absence of γ ray emission from a high $\dot{E}/d^2$ pulsar
- Radio & γ ray emission sites different in RPPs



Independent constraints from predictions of geometric light curve models

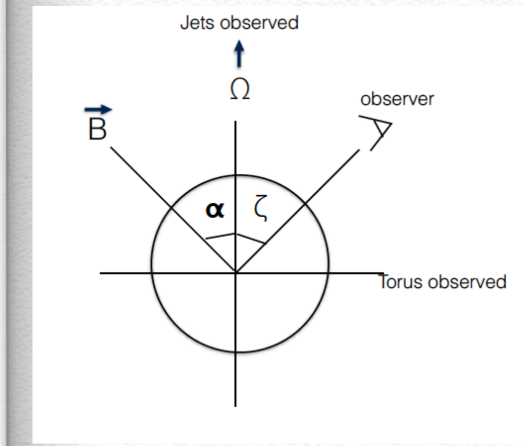
- Geometric light curve models from (Dyks & Rudak 2003) TPC and OG (Romani 1996) and hollow-cone radio beam model (Radhakrishnan & Cooke 1969) generated to match the observed radio pulse profile for different combinations of α, ζ (5°,5° grid)



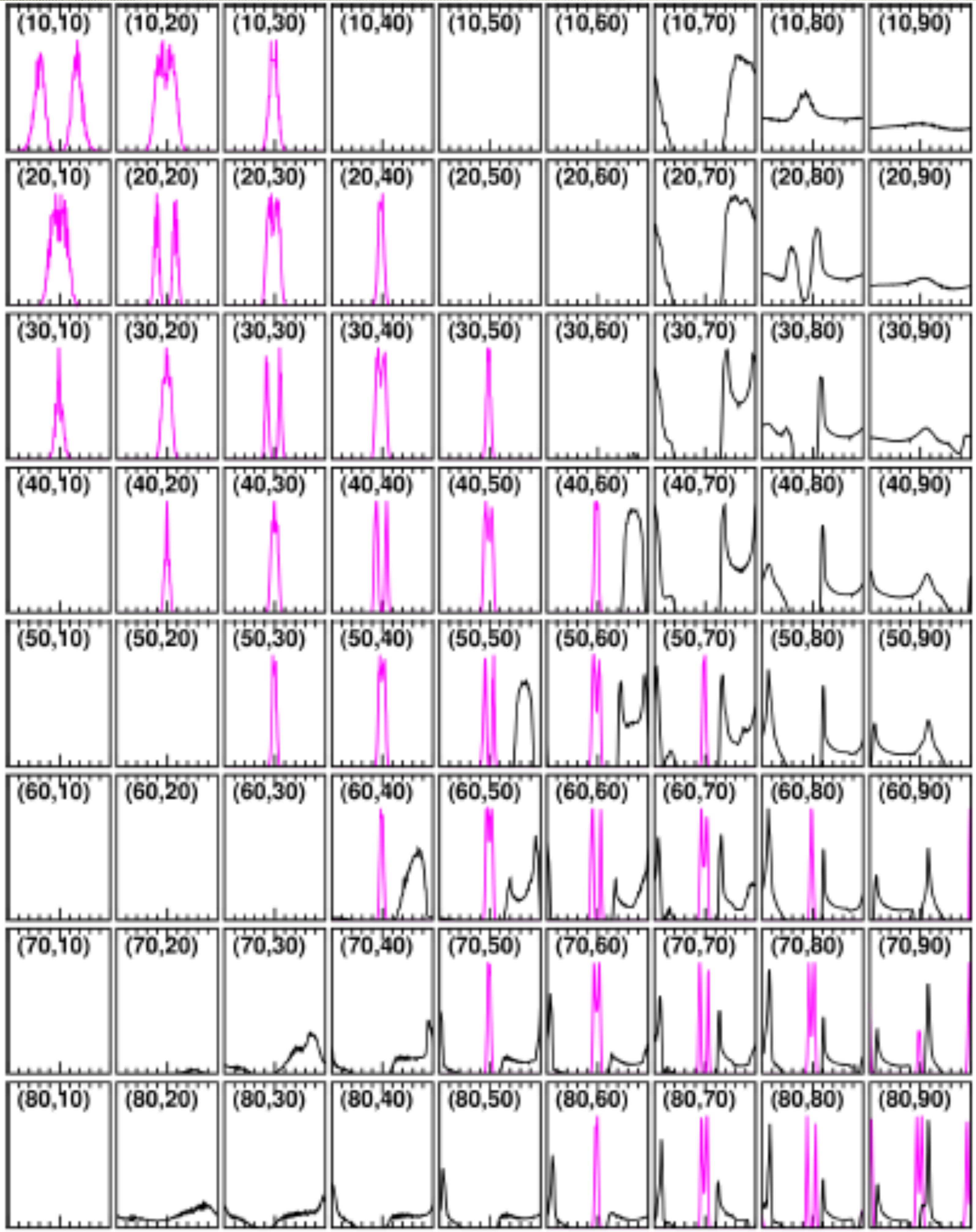


- Details of method in C. Venter, T. J. Johnson, and A. K. Harding 2012, ApJ, 744, 34

α, ζ 10° grid



Predicted OG γ-ray (black), radio (magenta) light curves. γ-ray light curves have been normalized globally so that maximum is unity

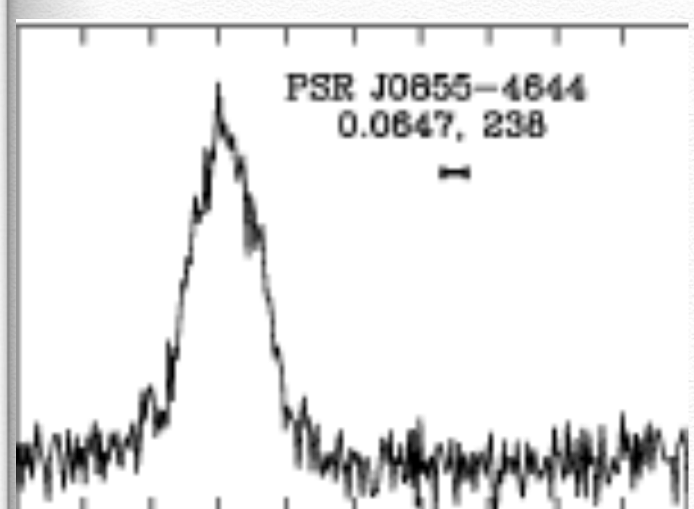


Independent constraints from predictions of geometric light curve models

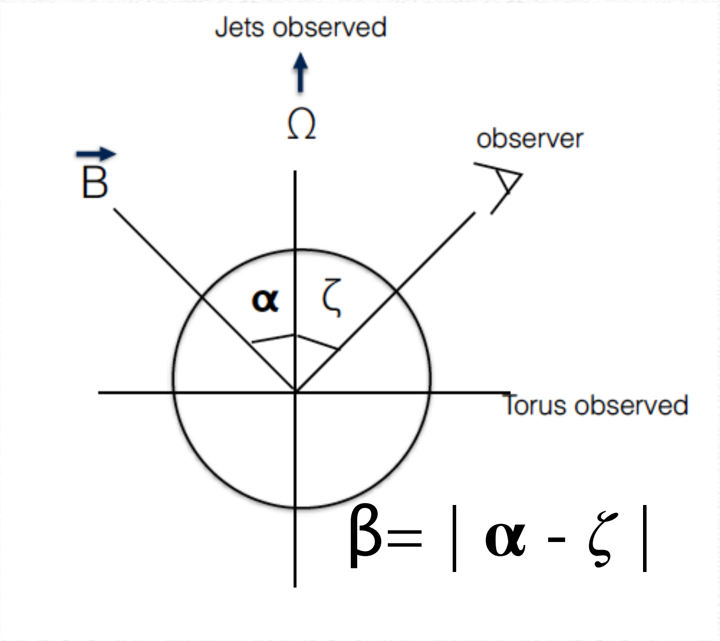
radio visibility & peak multiplicity

γ ray invisibility (non-detection)

radio profile fit



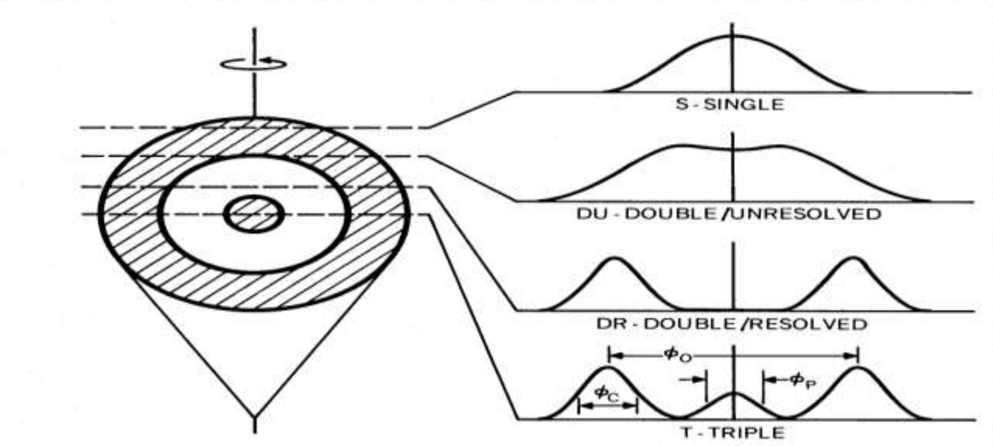
- constrain on ζ, $\boldsymbol{\alpha}$
- $\beta = |\boldsymbol{\alpha} - \zeta|$



Radio visibility & peak multiplicity: limits on β

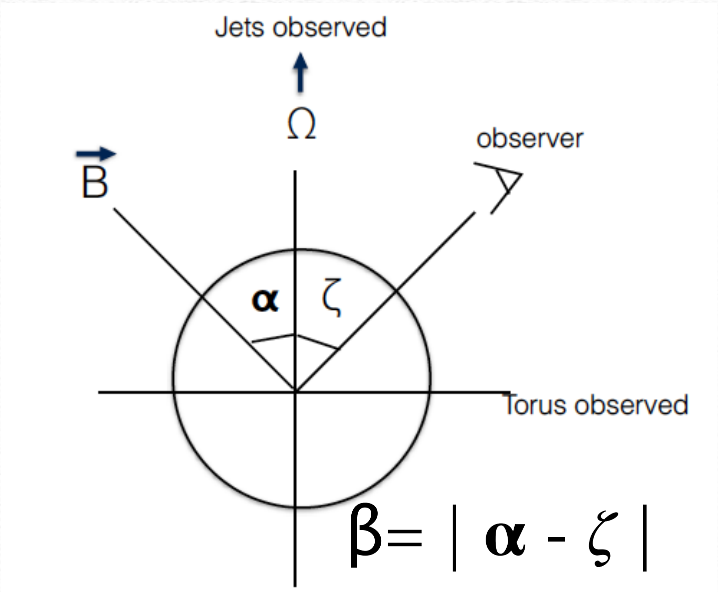
As β increases, radio beam progressively moves out of L.O.S and model predicts double peak, wide single peak, narrow single peak & no peak.

lower limit on β: single radio peak $\beta \gtrsim 10°$ (depends also on α)



lower limit on β: radio visibility $\beta \lesssim 30°$

$10° \lesssim \beta \lesssim 30°$



$\beta = |\alpha - \zeta|$

Independent constraints from predictions of geometric light curve models

radio visibility & peak multiplicity

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- constrain on ζ, $\boldsymbol{\alpha}$
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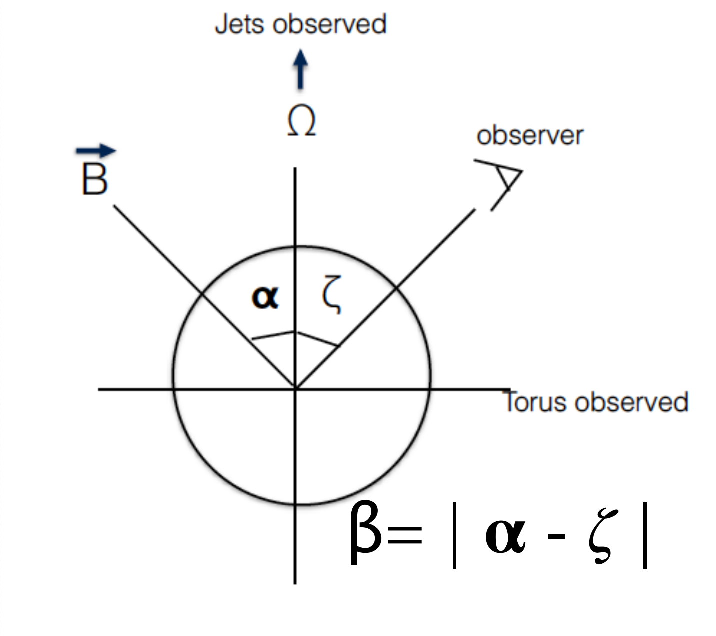
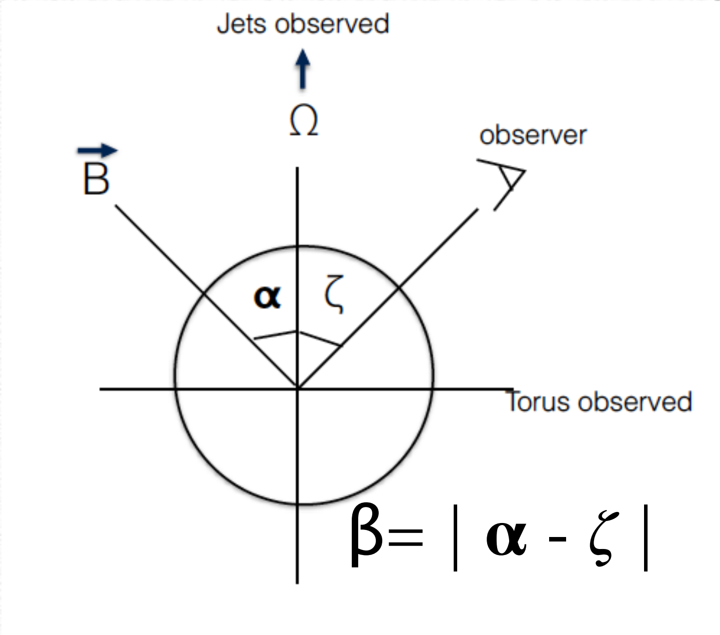


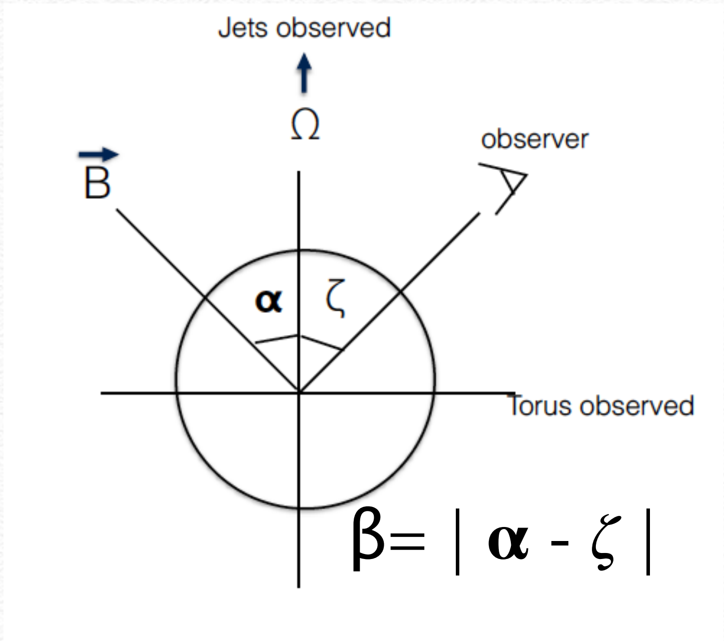
γ ray invisibility (non detection) limits on (α, ζ)

For OG: γ ray visible only at large $(\alpha, \zeta) \lesssim (55°,55°)$.
For TPC: γ ray visible almost at all angles, but low level emission are small (α, ζ)

γ ray is not detected

(α, ζ)≲(55°,55°)





$$10° \lesssim \beta \lesssim 30°$$

$$(\alpha, \zeta) \lesssim (55°, 55°)$$

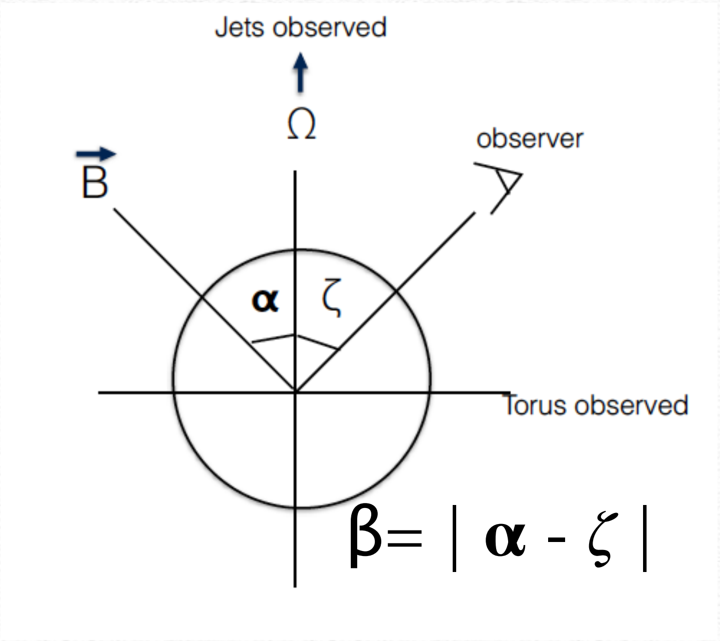
Independent constraints from predictions of geometric light curve models

radio visibility & peak multiplicity

γ ray invisibility (non-detection)

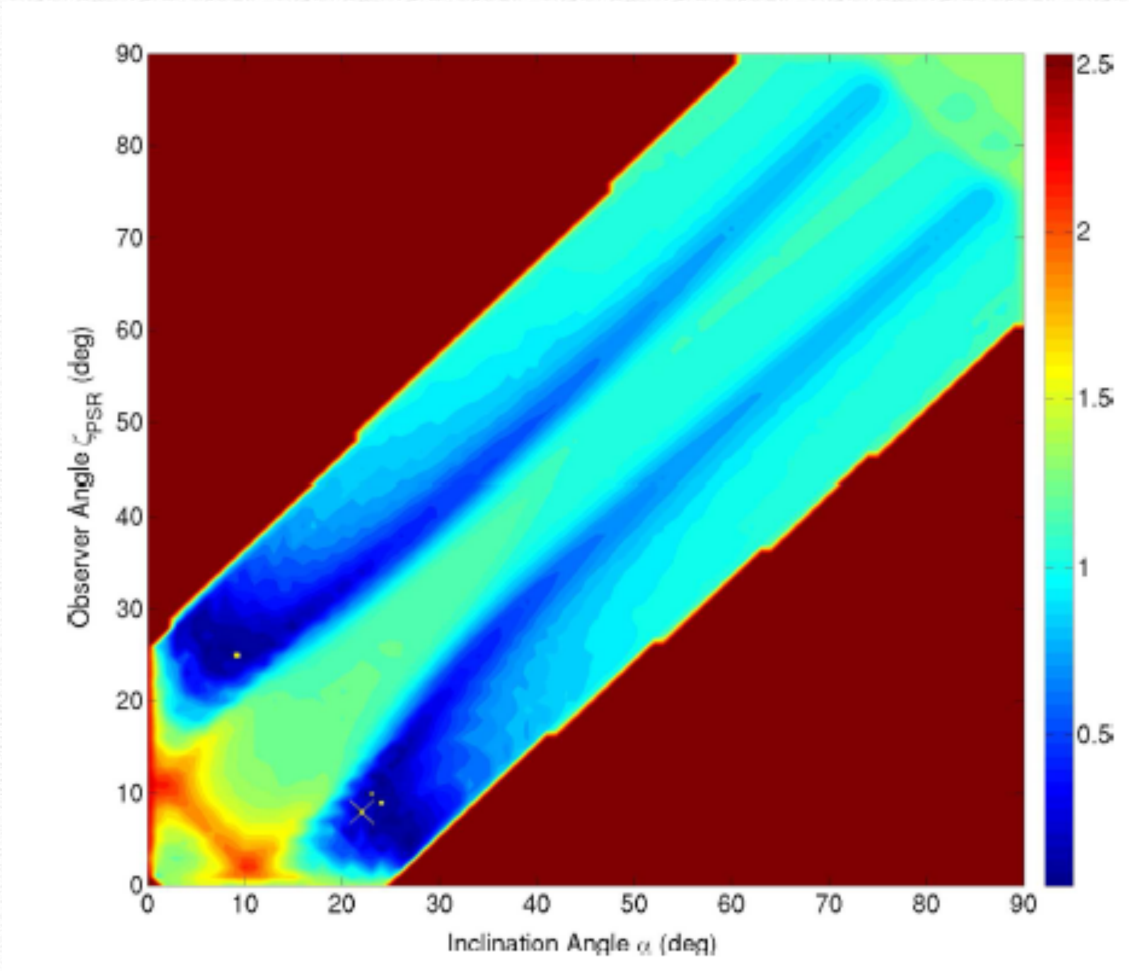
radio profile fit

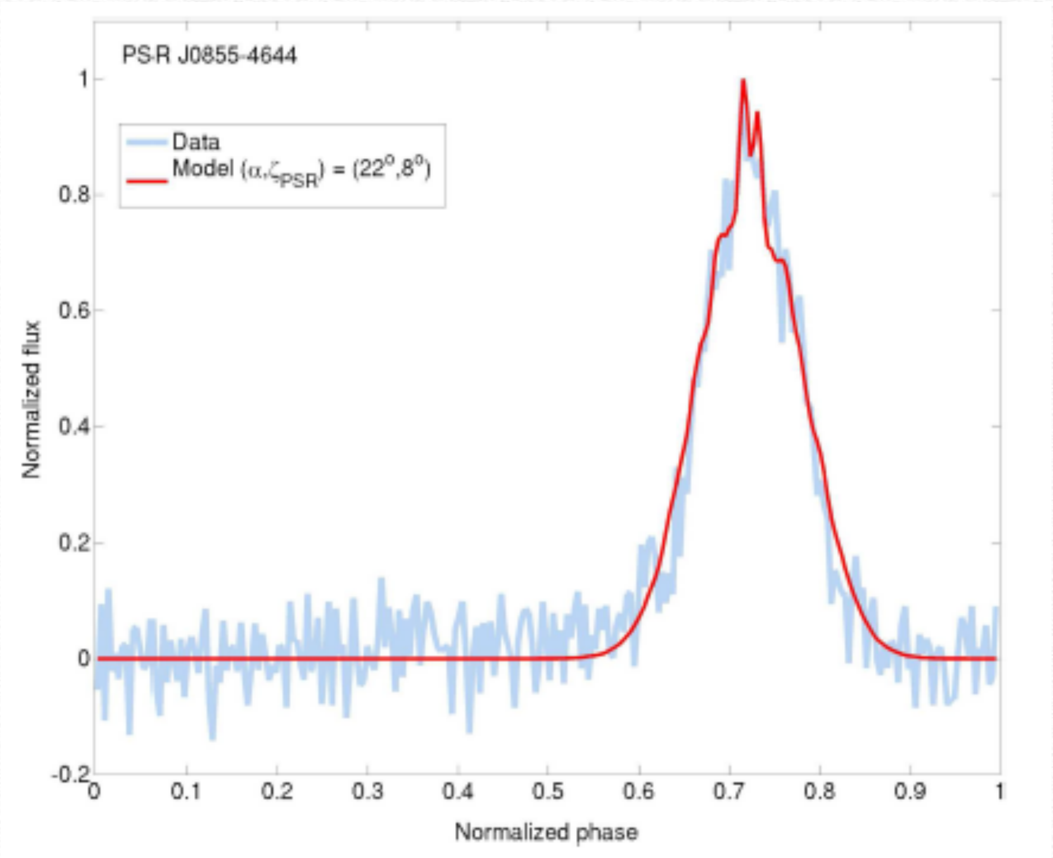
- constrain on ζ, $\boldsymbol{\alpha}$
- $\beta = |\boldsymbol{\alpha} - \zeta|$



$\log_{10}\chi^2/N_{dof}(\alpha, \zeta)$ map showing the best fit with the yellow cross

Best-fit radio light curves over plotted on the data

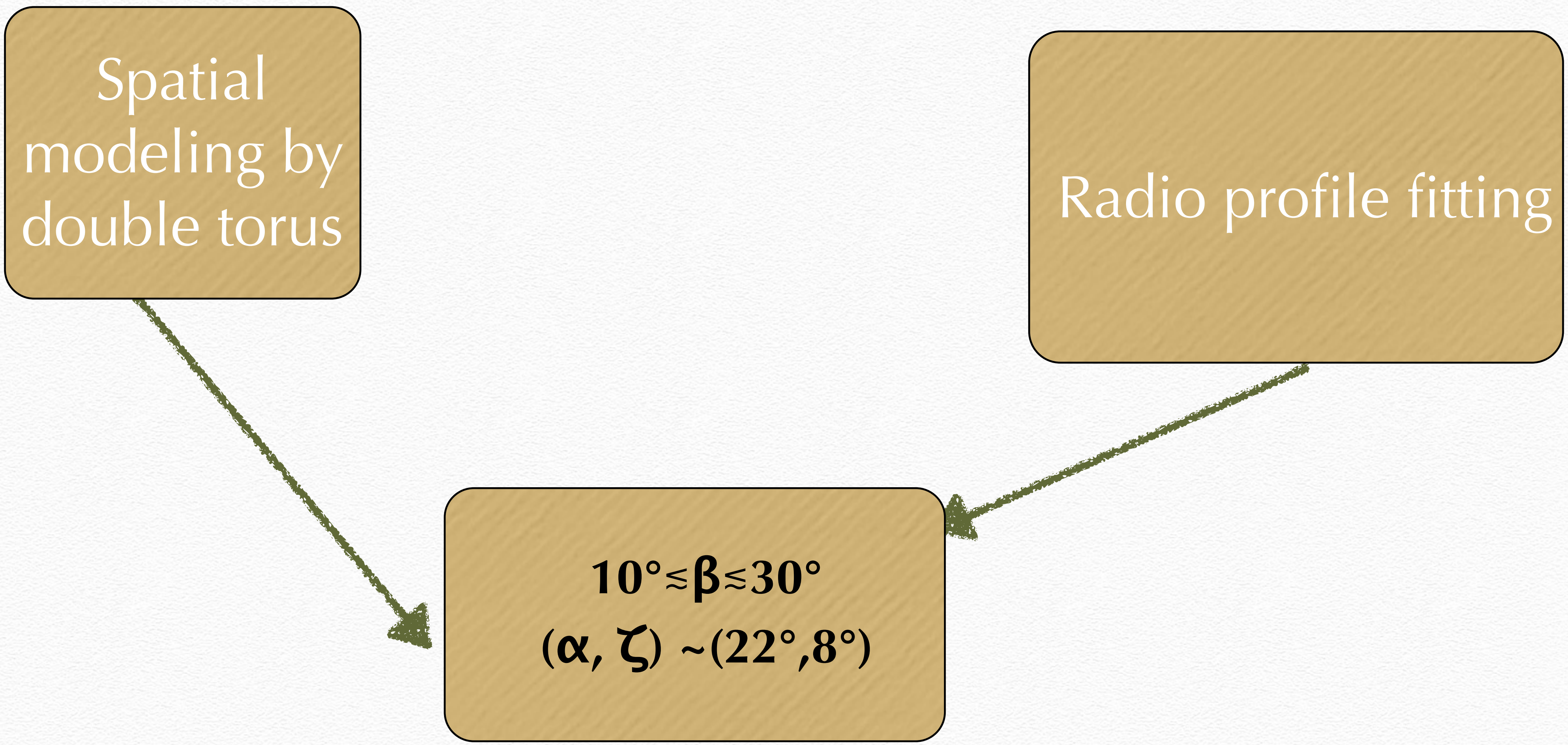




Best-fit at **(α, ζ) =(22°,8°)** map showing the best fit with the yellow cross
Alternative fit at **(α, ζ) =(9°,25°)** with almost comparable χ^2.
χ^2/N_{dof} ~ (285/255 & 294/255)

Geometry of PSR J0855-4644

Maitra, Acero & Venter, A&A, 2017, 597, 75



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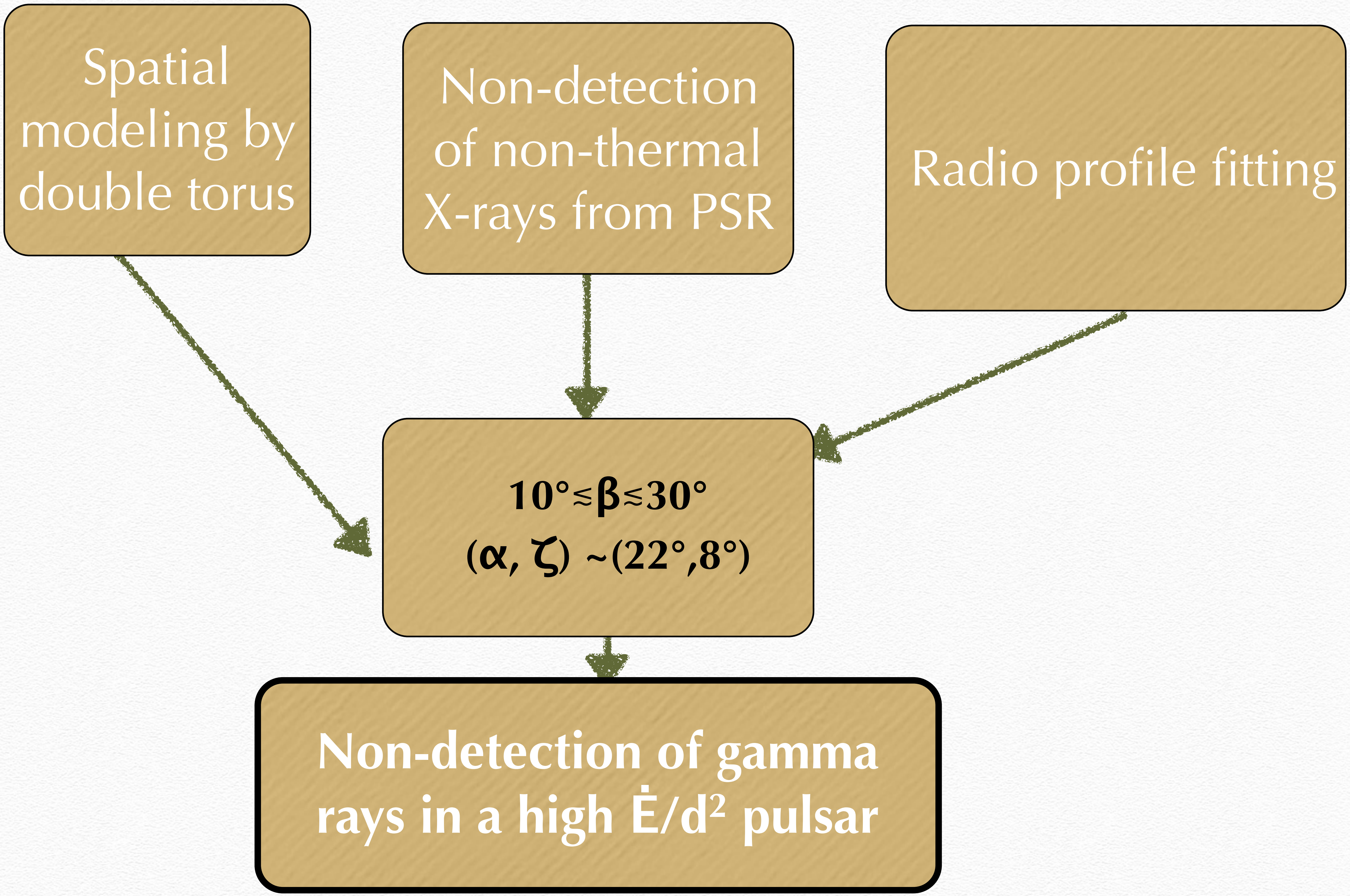
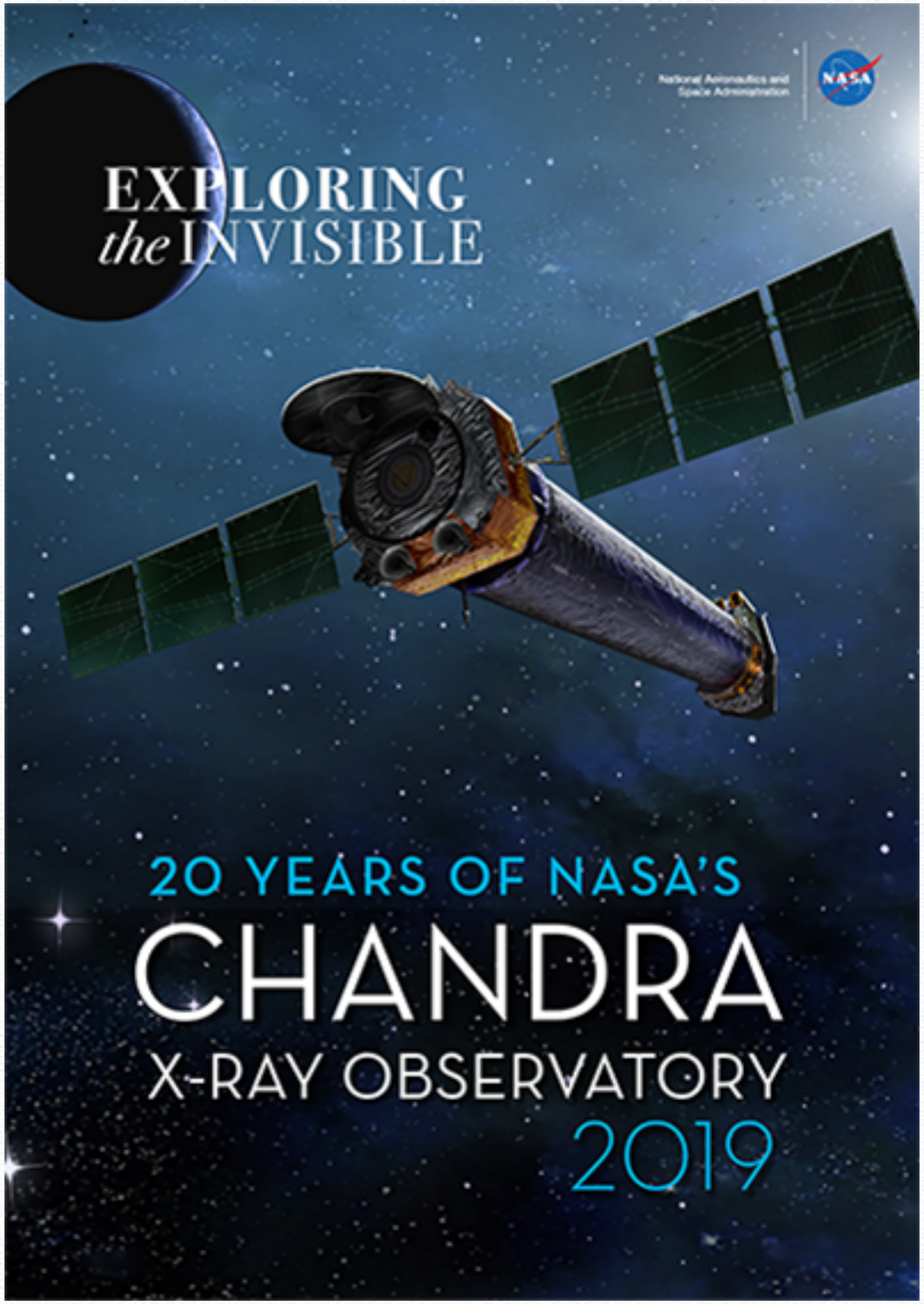
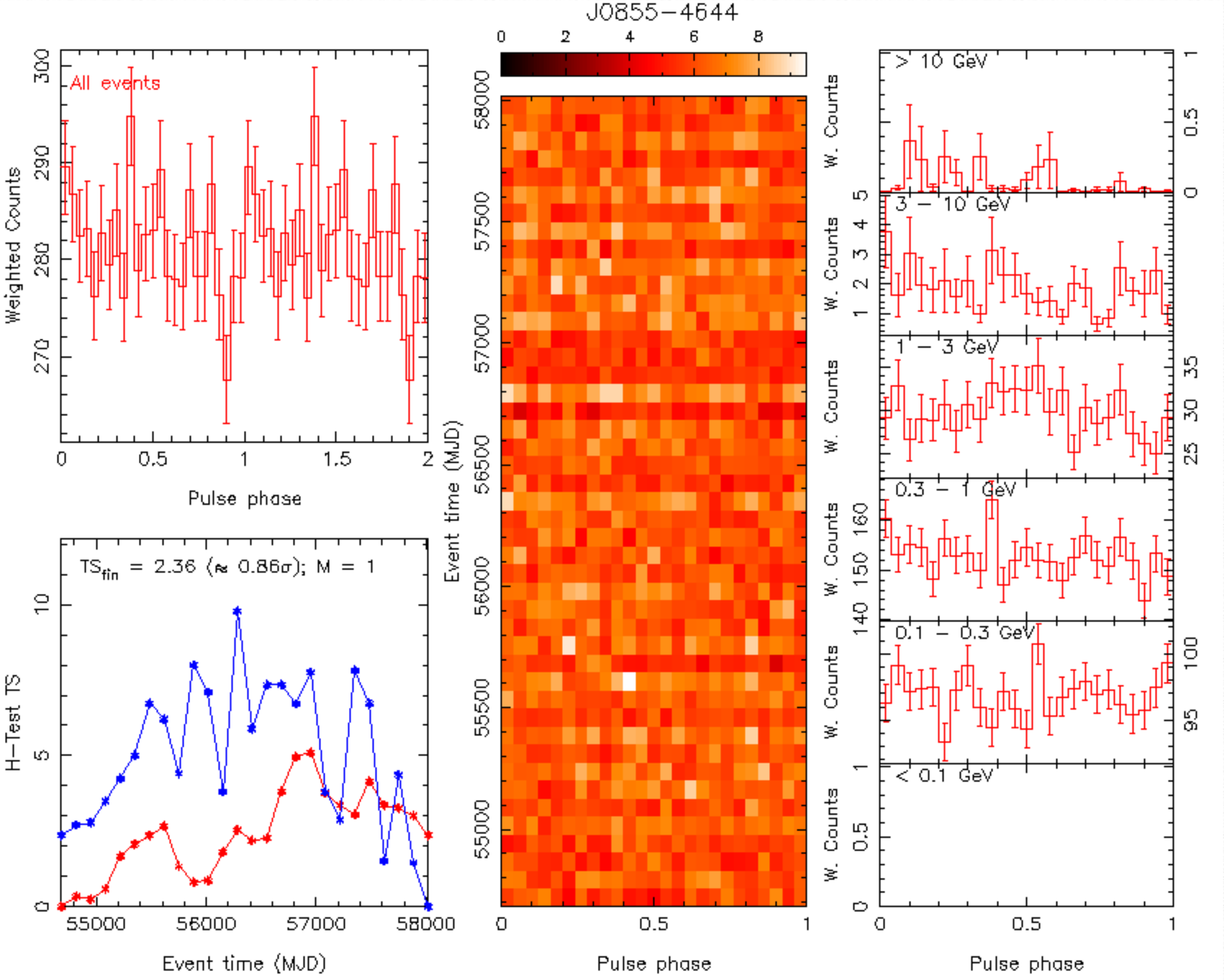


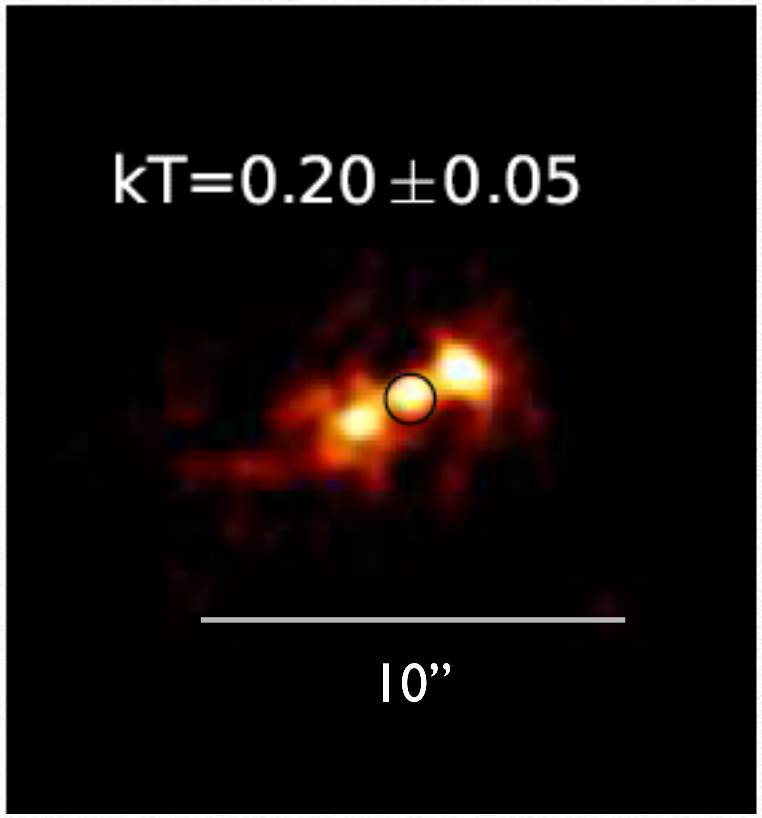

National Aeronautics and Space Administration
NASA
EXPLORING
the INVISIBLE
20 YEARS OF NASA'S
CHANDRA
X-RAY OBSERVATORY
2019

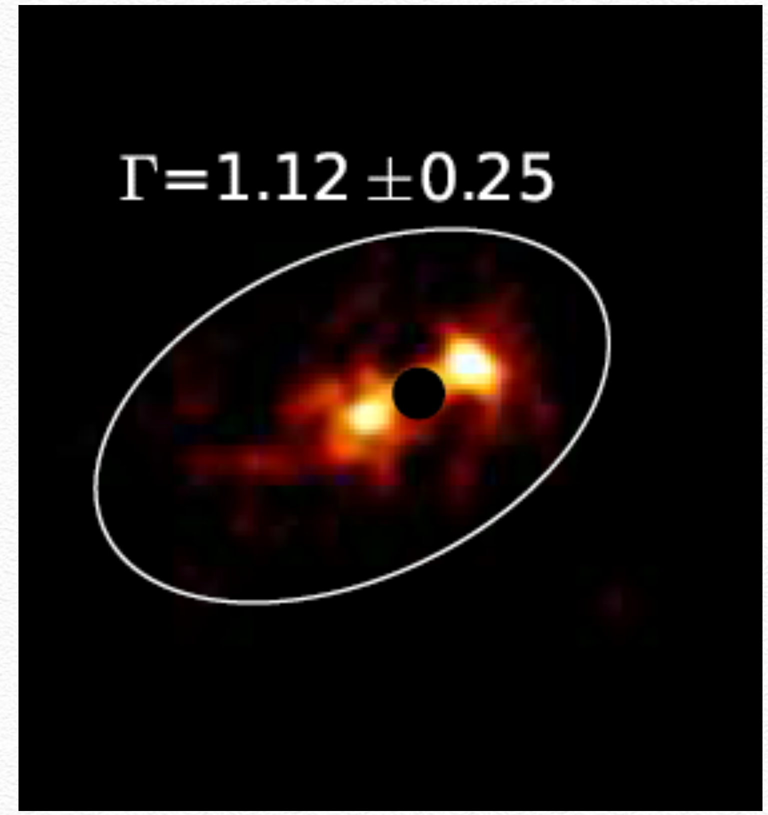
THANK YOU!



David Smith, Mathew Kerr (private comm)

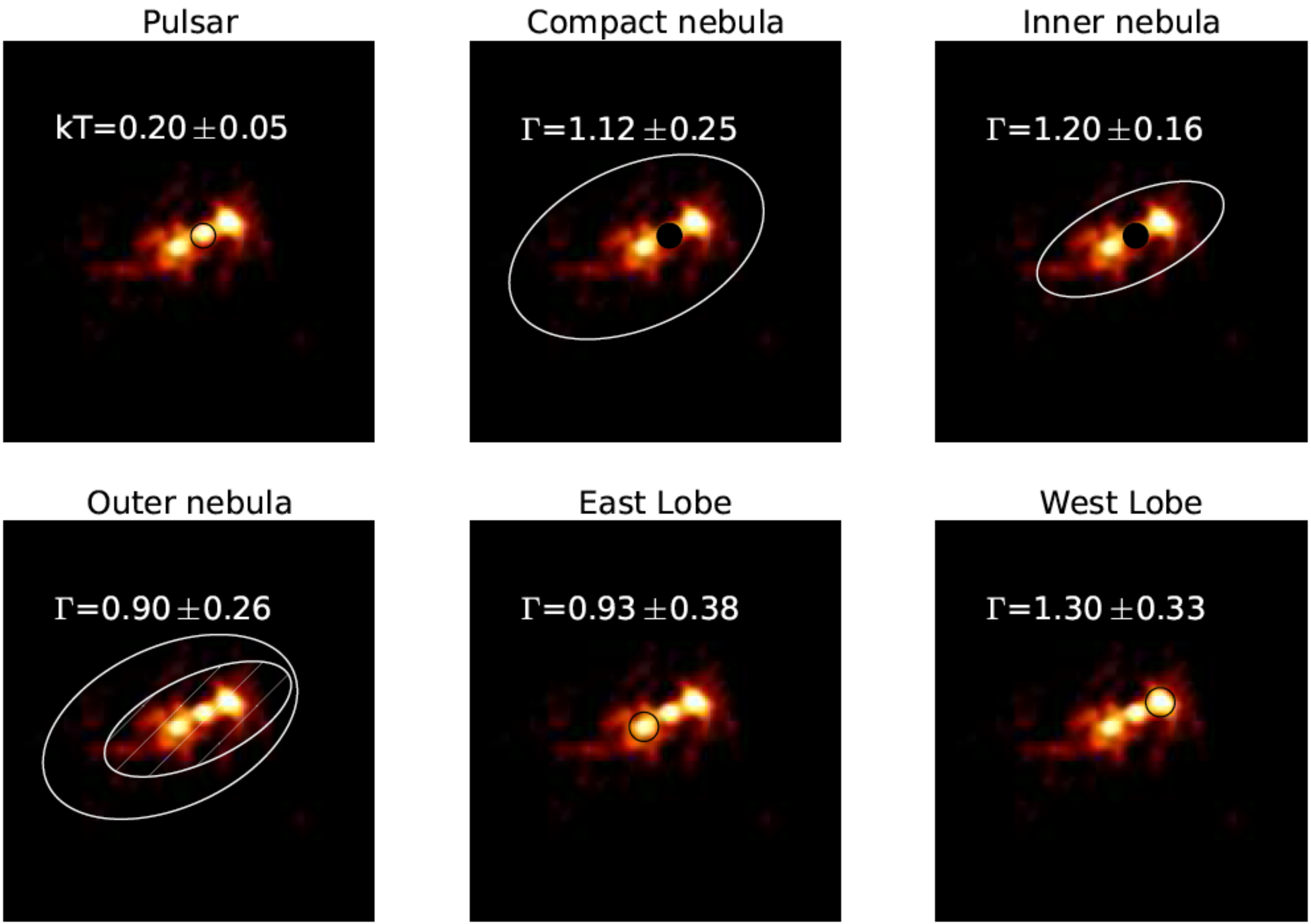
Faint soft pulsar & it's bright & hard nebula



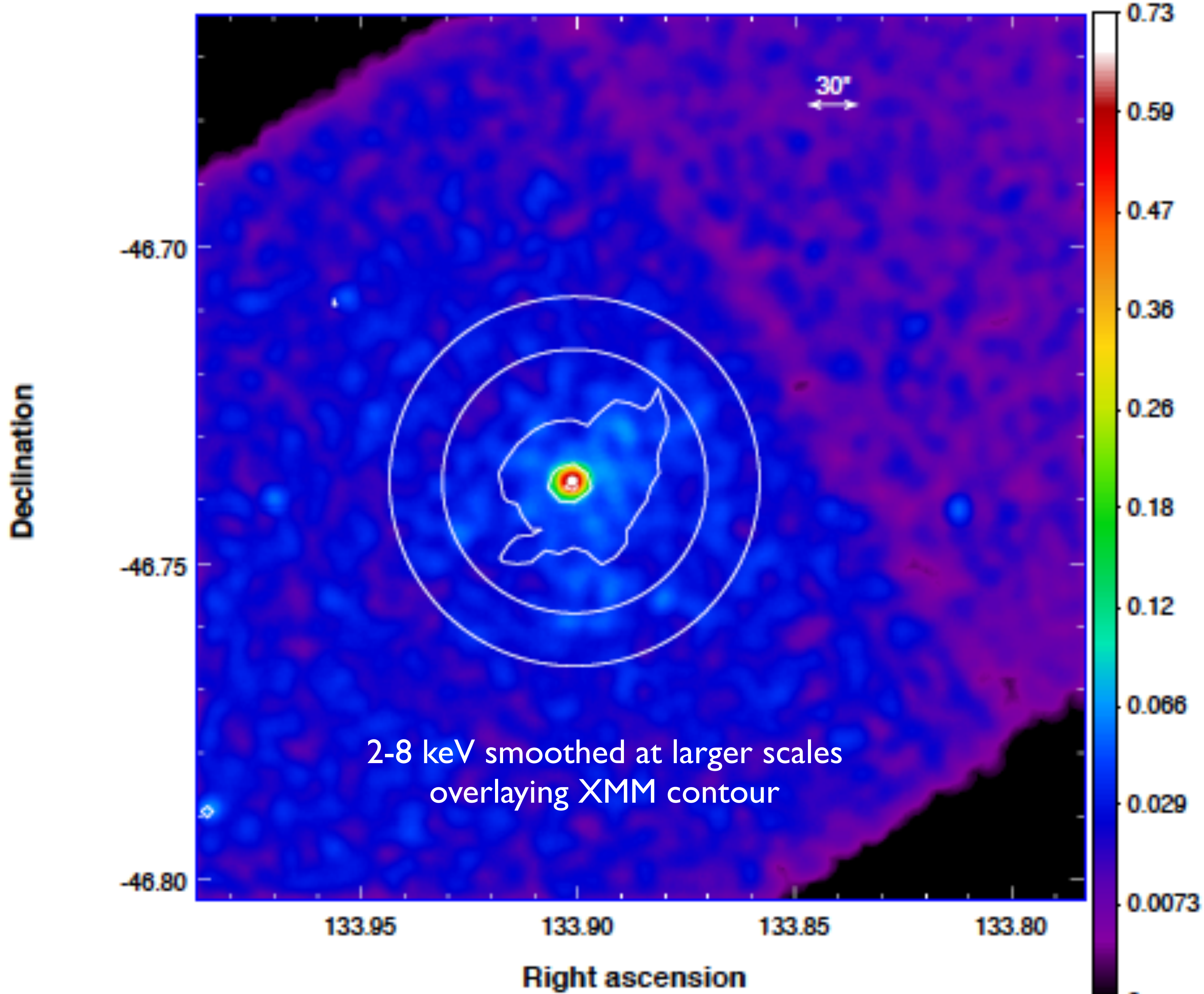


Lx (0.5-8) = 1.3 X 10^{30} erg s^{-1}
Reff ~ 1.5 km : emission from hot spot of neutron star

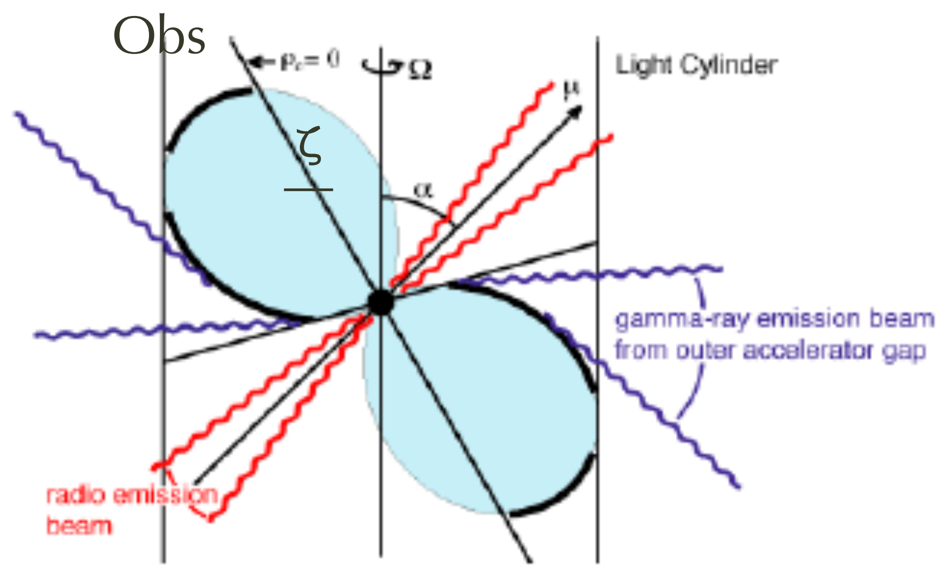
Lx (0.5-8) = 3.3 X 10^{31} erg s^{-1}
non-thermal emission
$\eta \equiv \dot{E}/Lx$ ~10-5
compact nebula ~0.06 pc (d=900 pc)


Pulsar
kT=0.20 ±0.05
Compact nebula
Γ=1.12 ±0.25
Inner nebula
Γ=1.20 ±0.16
Outer nebula
Γ=0.90 ±0.26
East Lobe
Γ=0.93 ±0.38
West Lobe
Γ=1.30 ±0.33

diffuse emission



Emission from rotation powered pulsars



picture courtesy Jerome Petri

- Polar cap (Daugherty & Harding 1996): Particle acceleration & radiation at the magnetic poles: **Radio**
- Outer Gap (Romani 1996): Particle acceleration & radiation between caustic and light cylinder: **X-rays and Gamma rays**
- Slot gap or Two-Pole-Caustic (TPC) model: (Dyks & Rudak 2003)
- Models of outer-gap emission of gamma rays predict $\zeta > 45$ deg and large $\alpha - \zeta > 30$ deg (Romani & Yadigaroglu 1995& references): Constraint on pulsar geometry

Independent constraints from predictions of geometric light curve models

- P=65 ms and ν=1.2 GHz sets the beam width for radio as

Radio beam width from a single altitude ~$\theta_{pc} \propto P^{-1/2}$

- Beam width in conjunction with ζ sets radio visibility of the pulsar
- **Derive α, ζ based on radio visibility, and gamma ray non-visibility -> Geometry**
- Geometric model, so does not predict flux, but match normalized pulse shape to the observed profile
- Details of method in reference **1)** C. Venter, A. K. Harding, L. Guillemot, 2009, ApJ, 707, 800 **2)** C. Venter, T. J. Johnson, and A. K. Harding 2012, ApJ, 744, 34