The pulsar contribution to the new EGRET γ-ray sources

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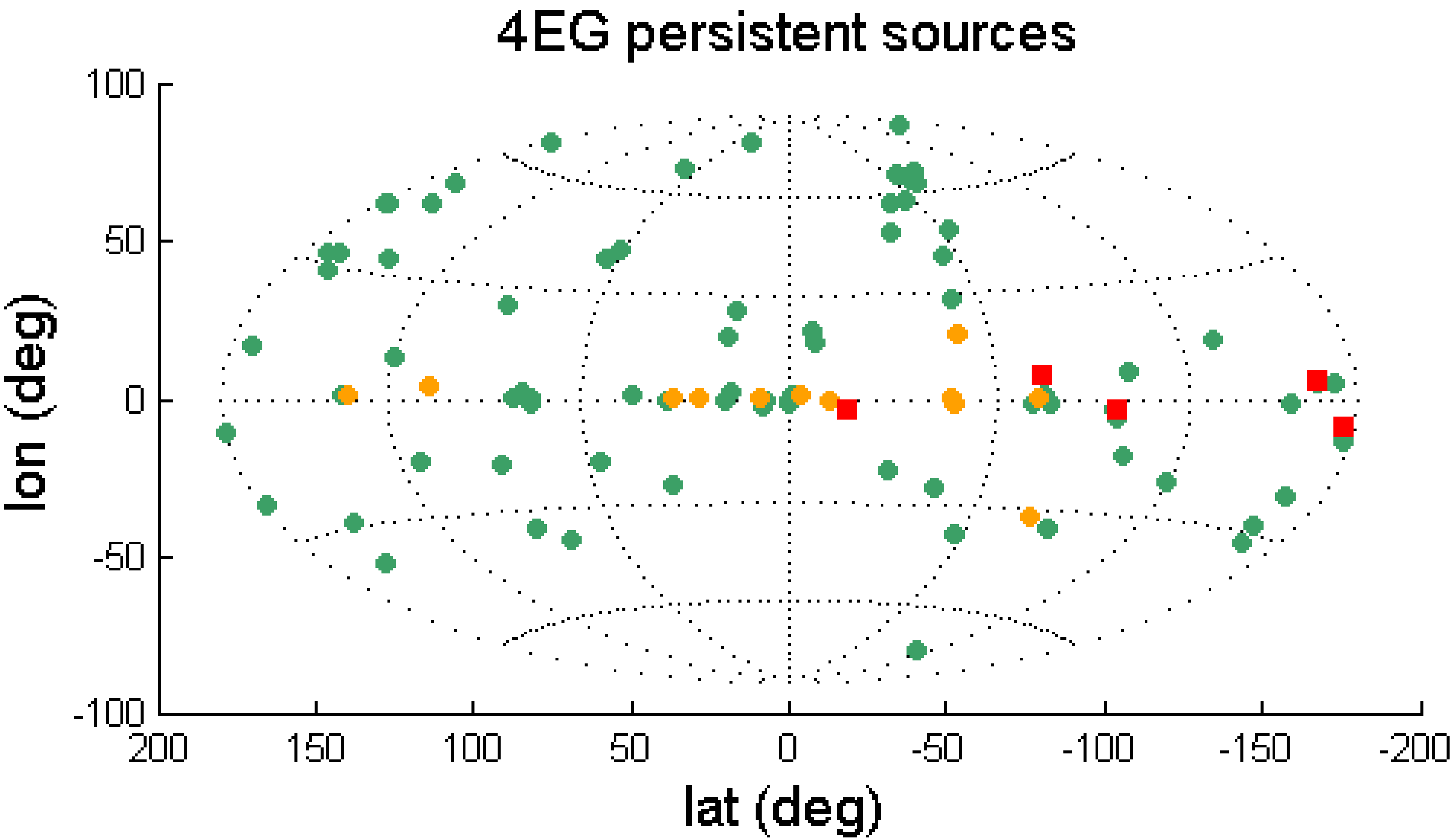
Rationale

Pulsars may largely contribute to the unidentified γ-ray sources at low and medium latitudes. The addition of a new component in the interstellar γ-ray background has recently led to a substantial revision of the EGRET sources, especially at medium latitudes. We compare their space and flux distributions with the predictions from the slot-gap and the outer-gap for pulsed emission. We use Monte-Carlo simulations of neutron stars matching the population of known radio pulsars. The γ-ray luminosity evolves with spin-down power and age. We use synthetic lightcurves based on the field lines geometry to compute the flux as a function of magnetic inclination and viewing angle. A detailed sensitivity map of the EGRET survey is used to compare to the sources.

new EGRET sources

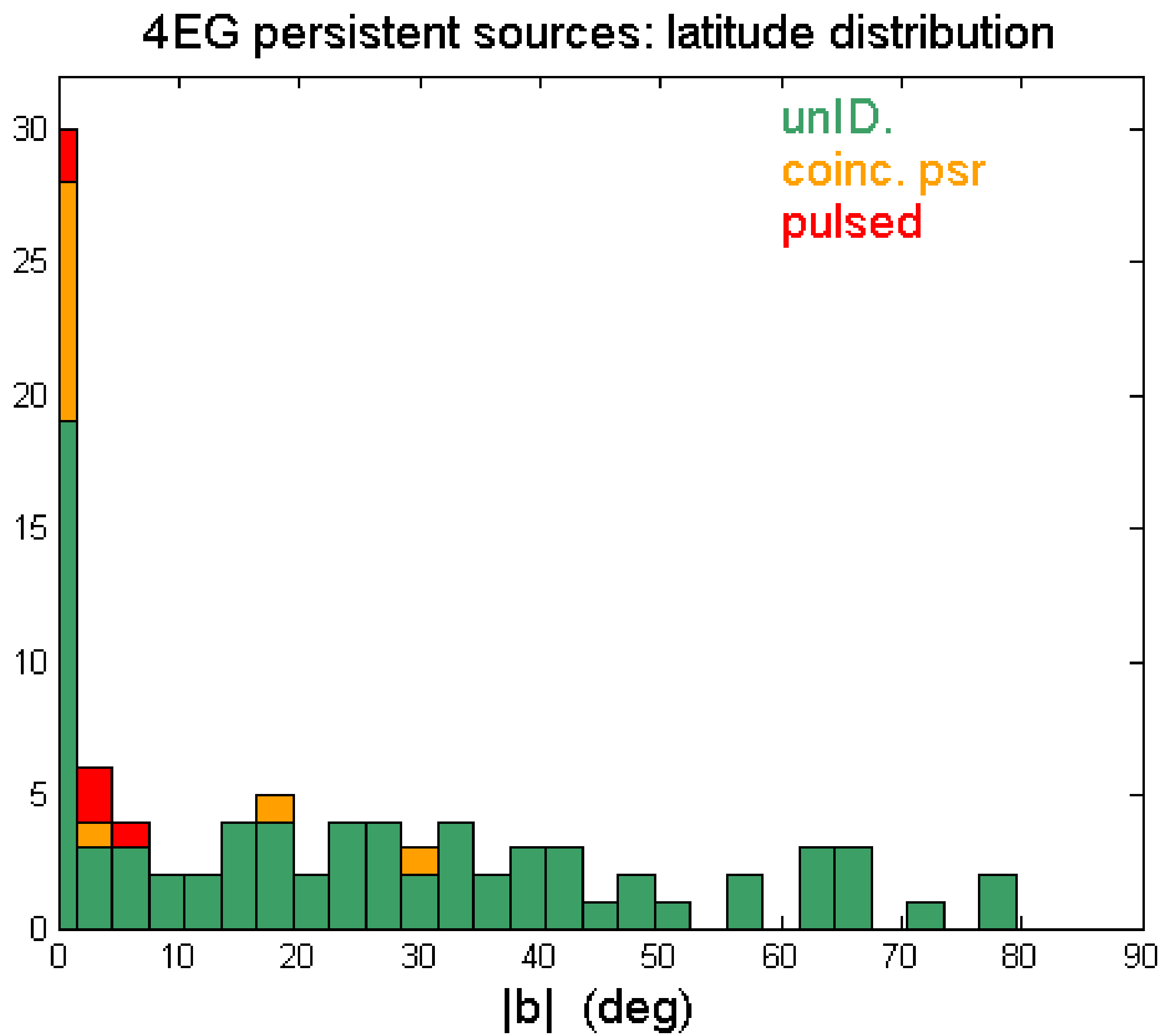
- new, brighter, interstellar γ-ray background
  - addition of massive envelopes of dark gas around the nearby CO clouds *(Grenier et al.'05)*
  - significant and structured additional emission at $|b| < 50°$
- numerous faint 3EG sources are not confirmed
  - in particular, most of the Gould Belt sources
- the new persistent sources exhibit
  - a large spread in latitude reminiscent of AGN
  - a mild concentration of Galactic objects at $|b| < 40°$
  - a sharp concentration of young objects in the plane

new EGRET sources



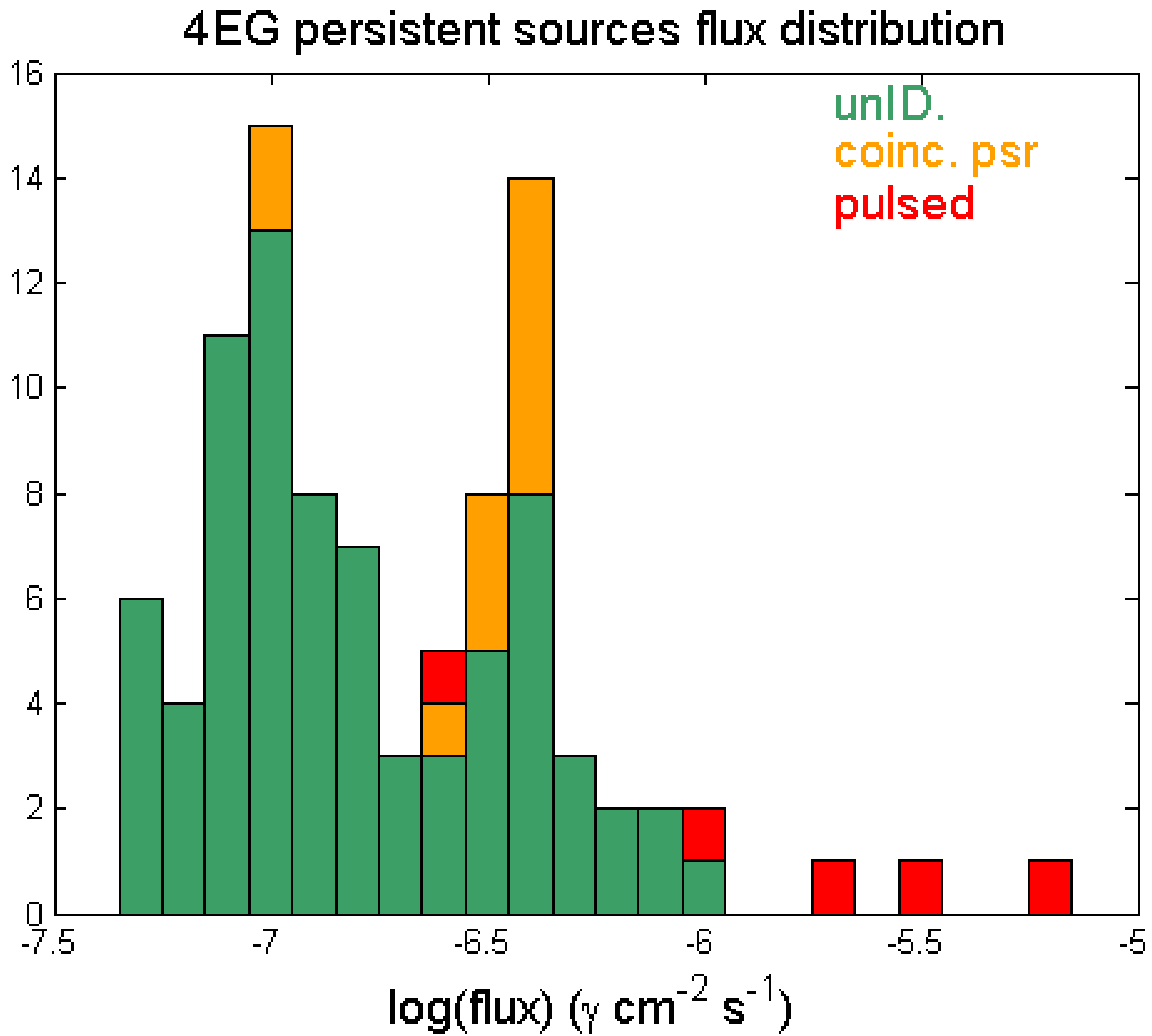
(l, b) distribution of the persistent sources detected over 9 years. The colours indicate unidentified sources, sources with a radio pulsar counterpart in the error box and known pulsed sources. Identified AGN are not displayed.

new EGRET sources



only the ATNF pulsar counterparts in the error box with a 1sr γ-ray luminosity at the pulsar distance $L_{1sr} < 10\ \dot{E}$ have been retained

new EGRET sources



neutron star simulations

- following Gonthier et al. ’04:
  - > 33 million objects evolved in the Galactic potential
  - using the new velocity distribution *(Hobbs et al. ’05)*
  - constant birth rate over 1 Gyr
  - random initial periods between 1 and 150 ms
  - 2 gaussian B distributions around $10^{8.75}$ and 10^{9} T at birth, with a decay timescale of 2.8 Myr
  - random magnetic inclinations $0° < \alpha < 90°$
  - random viewing angles $0° < \zeta < 180°$
- radio emission described in Gonthier et al. ’04
  - simulated objects scaled to match the number of radio pulsars detected in 9 surveys

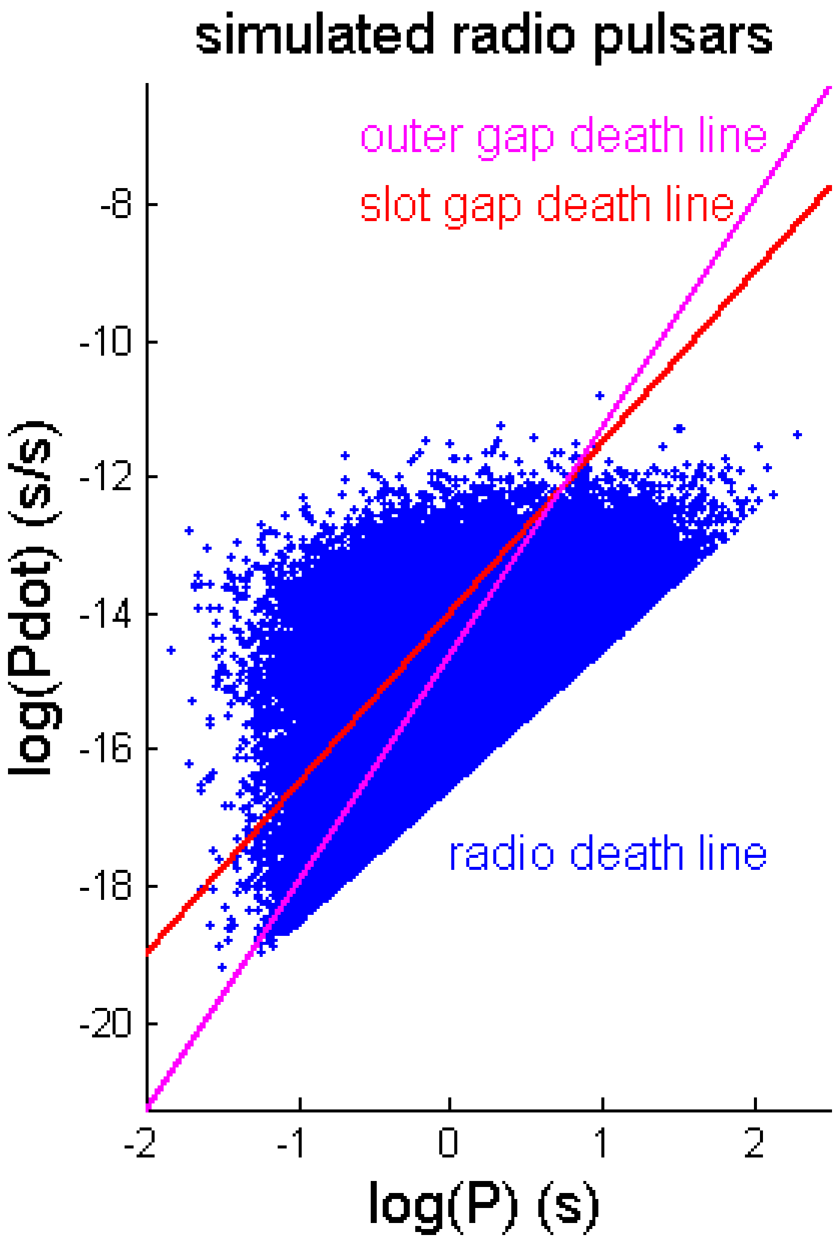
simulated pulsars

- ICS death line for radio emission
- curvature radiation pair death line for the slot gap *(Muslimov & Harding '03)*

$$\log \dot{P} \geq 2.5 \log P - 14.0$$

- death line for a fractional outer-gap size f_s = 1 *(Zhang et al. '04)*

$$\log \dot{P} \geq \frac{10}{3} \log P - 14.6$$



slot-gap model for γ rays

- luminosity $\quad L_\gamma = \varepsilon_\gamma L(e_1^\pm) \quad \varepsilon_\gamma = 0.1$ was adopted

$$L_\gamma = 0.0517\,\varepsilon_\gamma\,\dot{E}\;P_{0.1}^{3}\,B_8^{-12/7}\,I_{38}^{-9/7}\left[0.123\cos^2\alpha + 0.512\theta_{PC}^2\sin^2\alpha\right] \quad \text{for } B < 0.1B_{cr}$$

$$L_\gamma = 0.0065\,\varepsilon_\gamma\,\dot{E}\;P_{0.1}^{3}\,B_8^{-9/7}\,I_{38}^{-9/7}\left[0.123\cos^2\alpha + 0.512\theta_{PC}^2\sin^2\alpha\right] \quad \text{for } B > 0.1B_{cr}$$

- beam aperture

$$\Omega_\gamma = 25.08\,\theta_{PC}^2\,P_{0.1}\,B_8^{-4/7}\,I_{38}^{-3/7} \quad \text{for } B < 0.1B_{cr}$$

$$= 12.54\,\theta_{PC}^2\,P_{0.1}\,B_8^{-3/7}\,I_{38}^{-3/7} \quad \text{for } B > 0.1B_{cr}$$

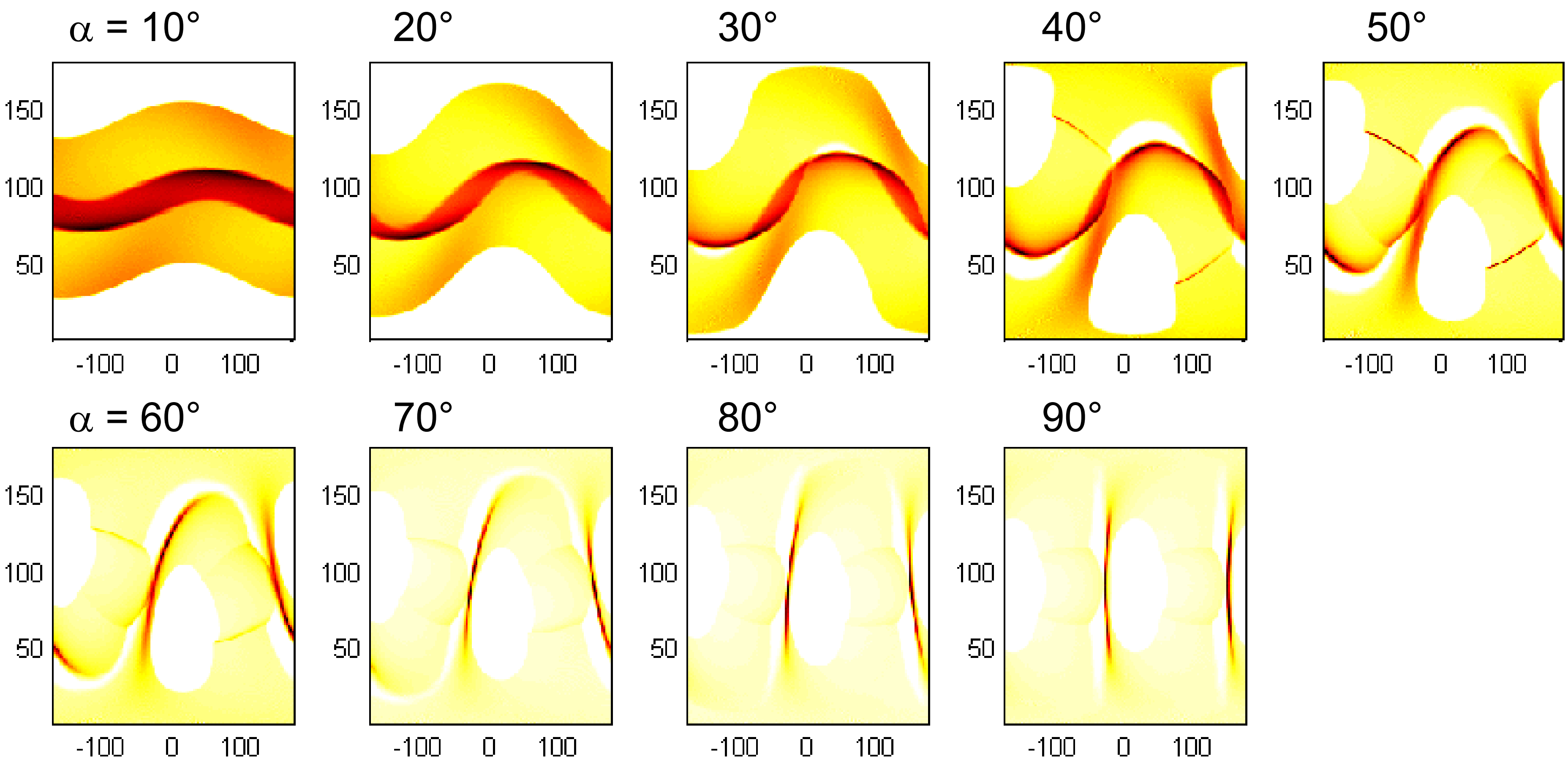
- beam pattern and evolution

Muslimov & Harding '03

  - following the phase-plot with α and ζ_{obs}
  - normalized to the mean beam intensity to account for its evolution with P and Pdot

$$\bar{I} = \left\langle \frac{dL}{d\Omega} \right\rangle_{\text{phaseplot}} = \frac{2\,L_\gamma}{\Omega_\gamma} = f(P,\dot{P})$$

slot-gap phase-plots



radiation pattern with phase (x axis) and viewing angle (y axis) for different magnetic inclinations for the slot gap

after Dyks & Rudak '03

outer-gap model for γ rays

❖ luminosity

$$L_\gamma = 1.36\,10^{26}\ \mathrm{W}\ \ P^{-2/7}\ B_8^{2/7}\ \eta^3(\alpha,P,B) \quad \text{for } L_\gamma < \dot{E}$$

- the $\eta < 2$ correction with α has not yet been implemented

Zhang et al. '04

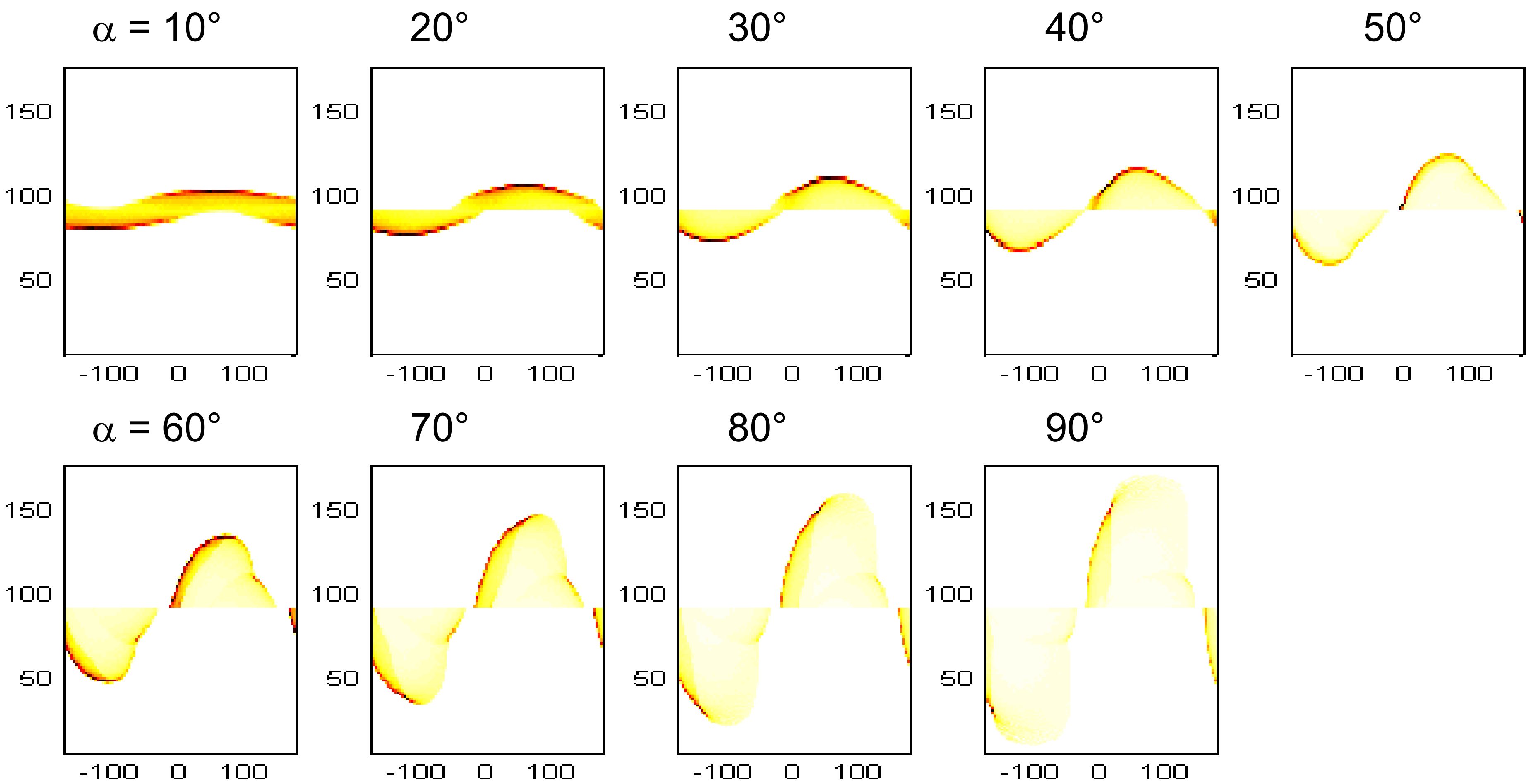
❖ beam aperture

- calculated from the phaseplot with α
- close to the $\alpha^{1/2}$ dependance given in Zhang '00

❖ beam pattern and evolution

- following the phaseplot with α and ζ_{obs}
- no beam evolution with P and Pdot

outer-gap phase-plots



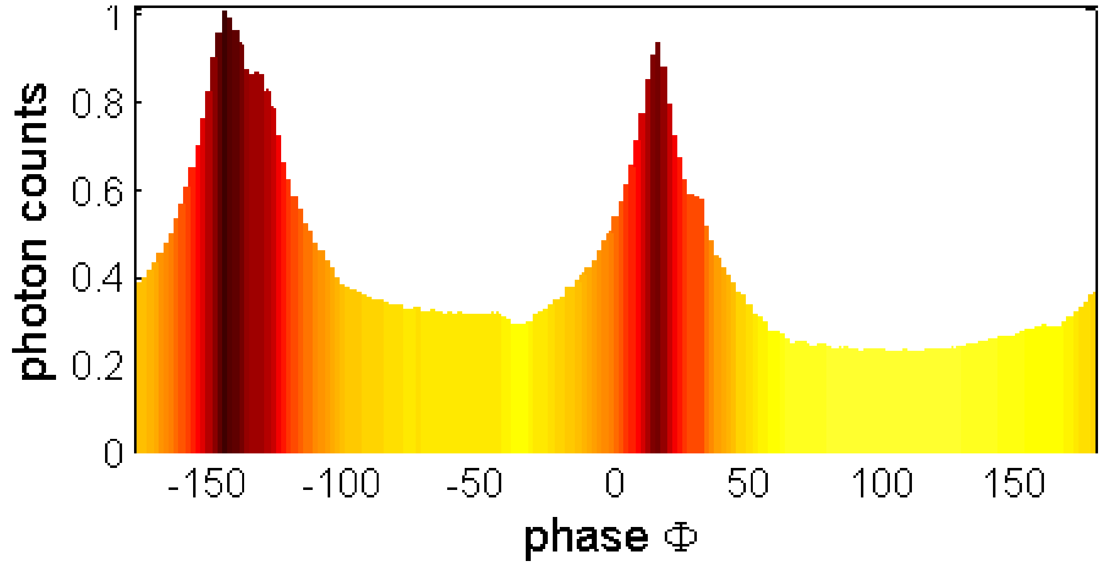
radiation pattern with phase (x axis) and viewing angle (y axis) for different magnetic inclinations for the outer gap

γ-ray fluxes

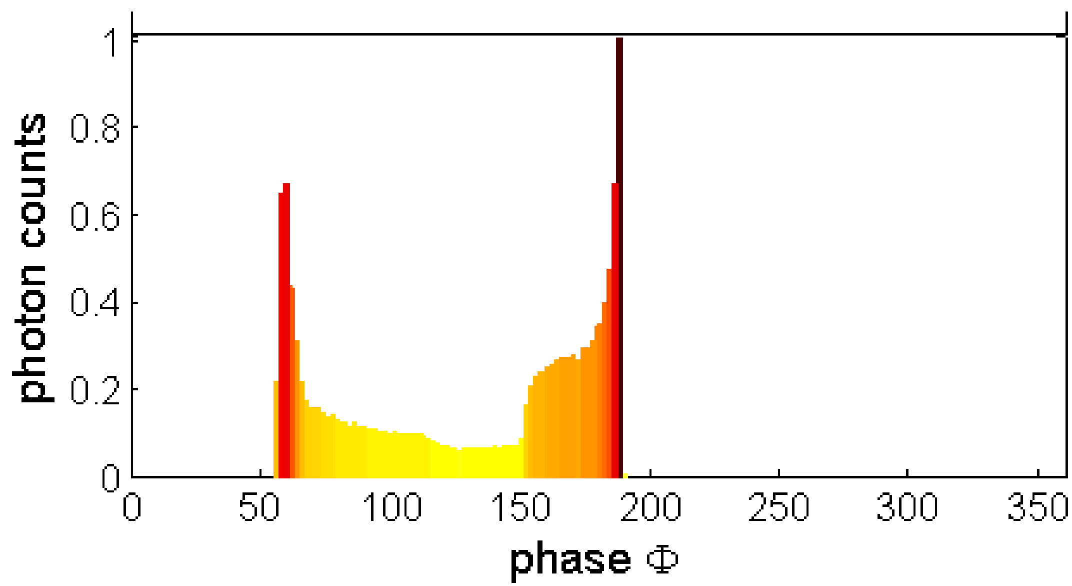
- energy flux derived from the lightcurves for α and ζ

$$\nu F_{\nu} = \frac{\int I(\alpha,\zeta,\varphi)\,d\varphi}{2\pi D^2}$$

- spectral hardening from $E^{-2.1}$ to $E^{-1.3}$ with log(age) to translate the energy flux in photon flux

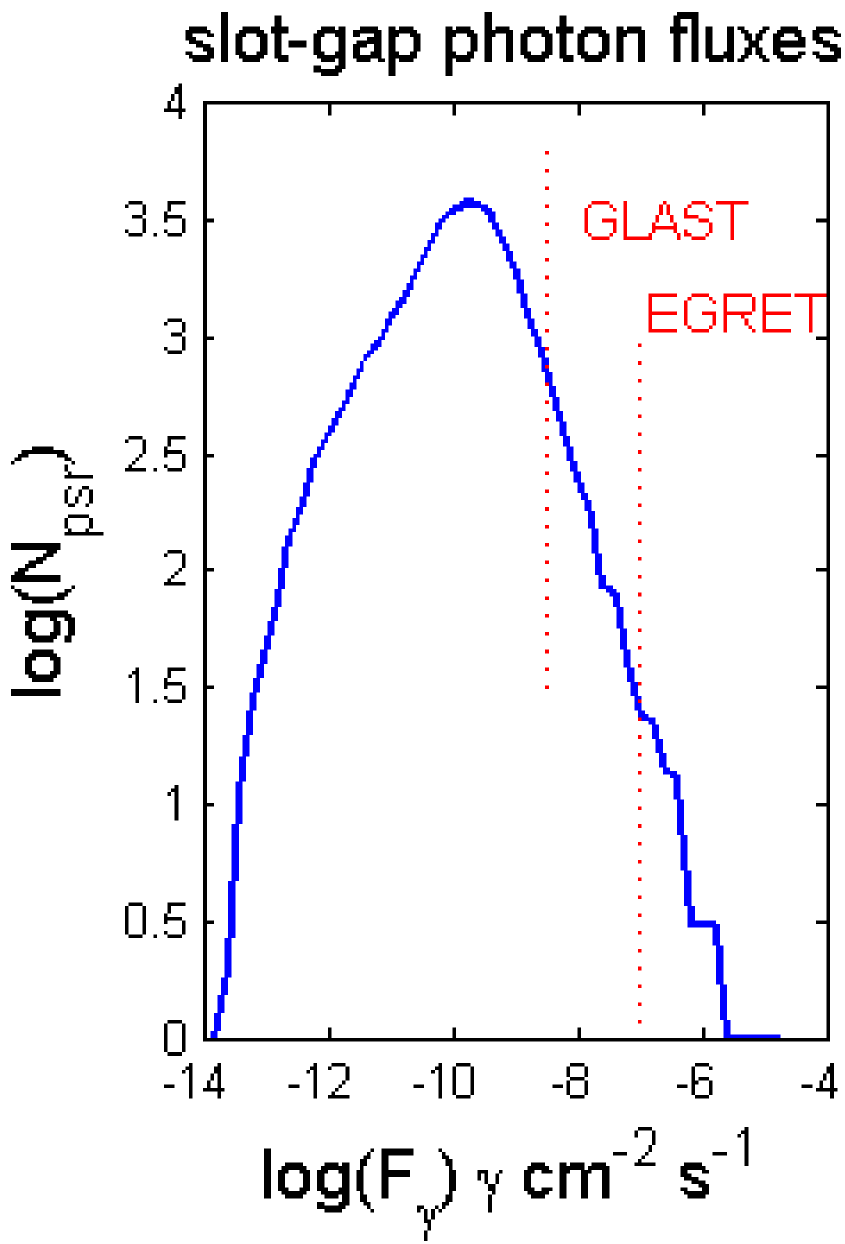


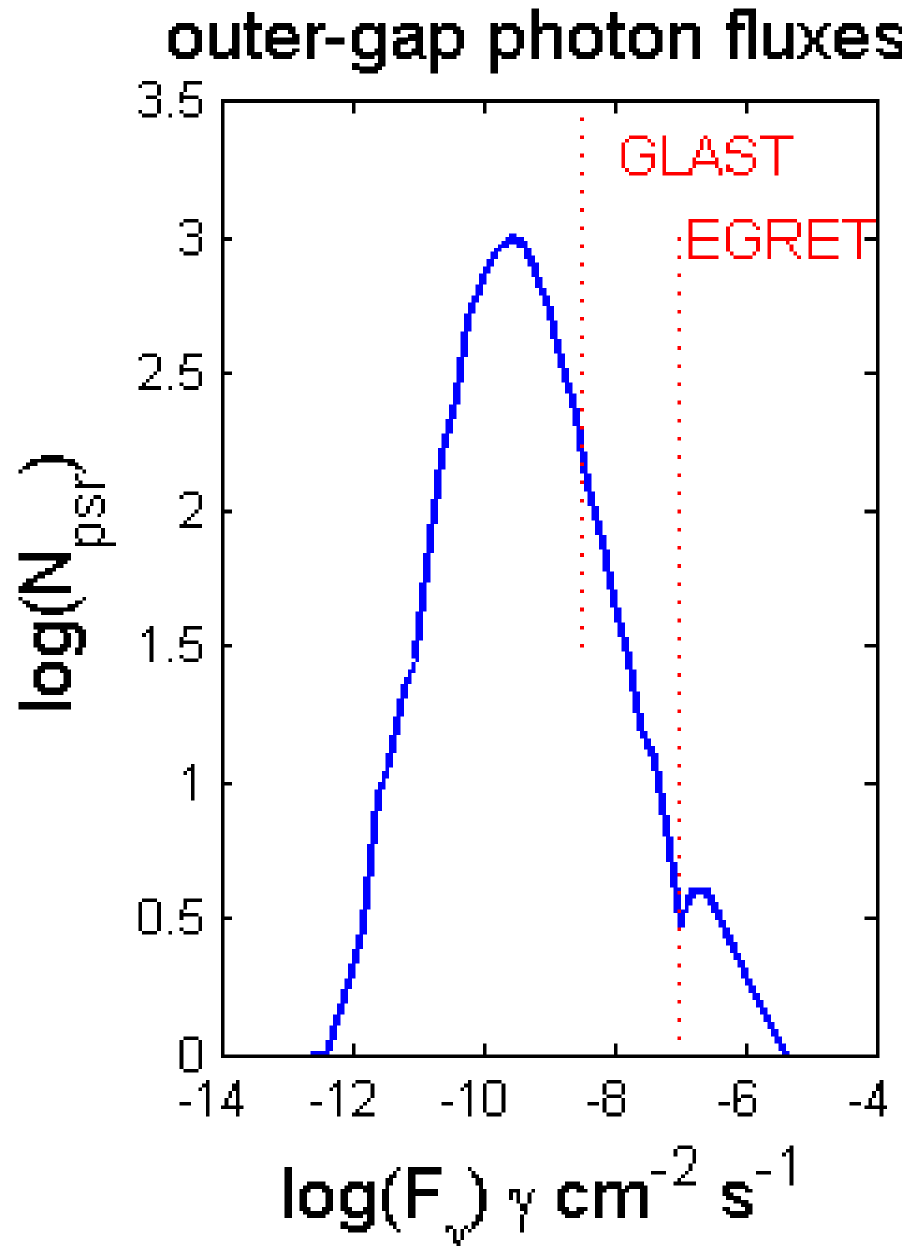
sample slot-gap lightcurve for α = 45°, ζ =100°



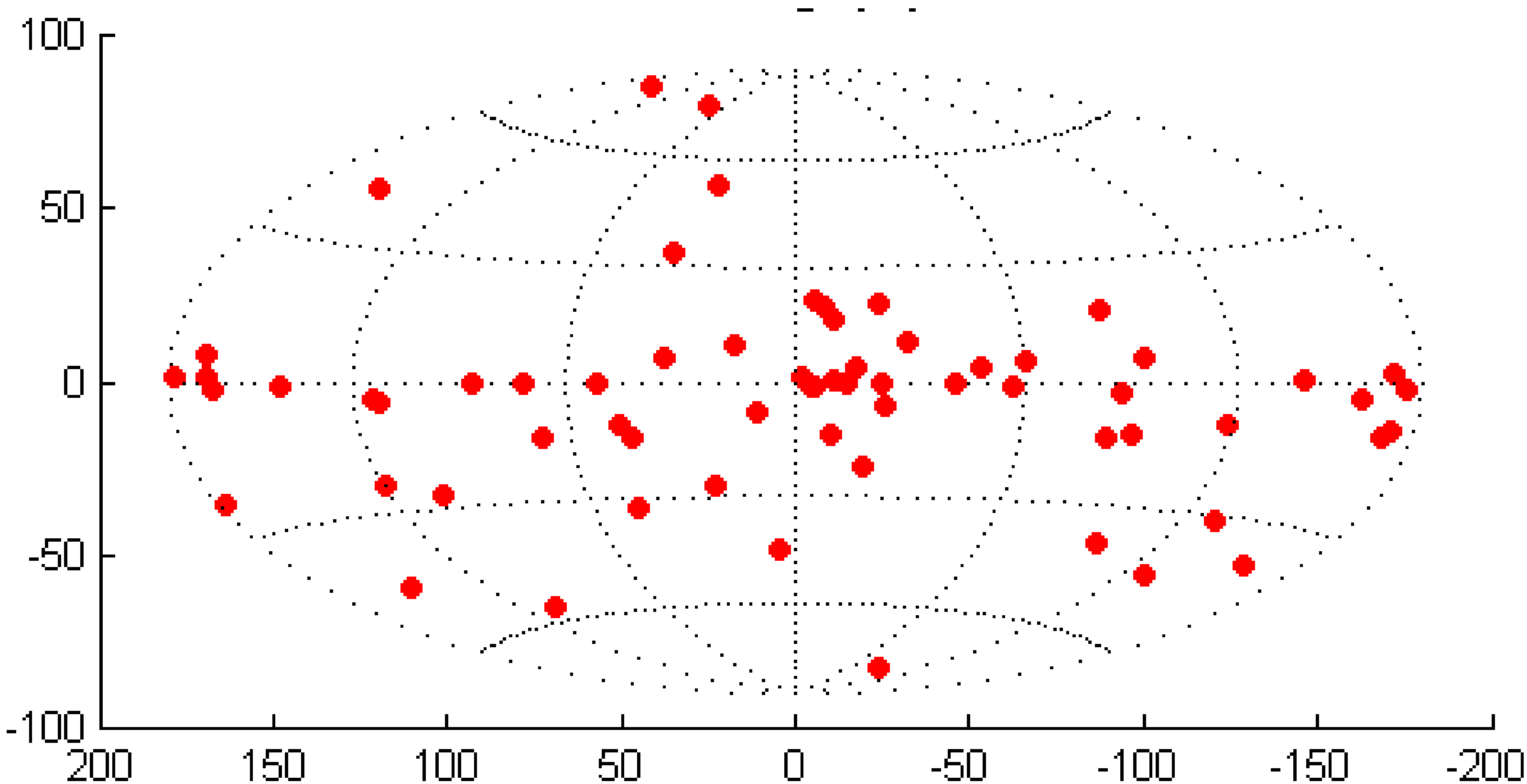
sample outer-gap lightcurve for α = 65°, ζ =80°

predicted γ-ray flux distributions



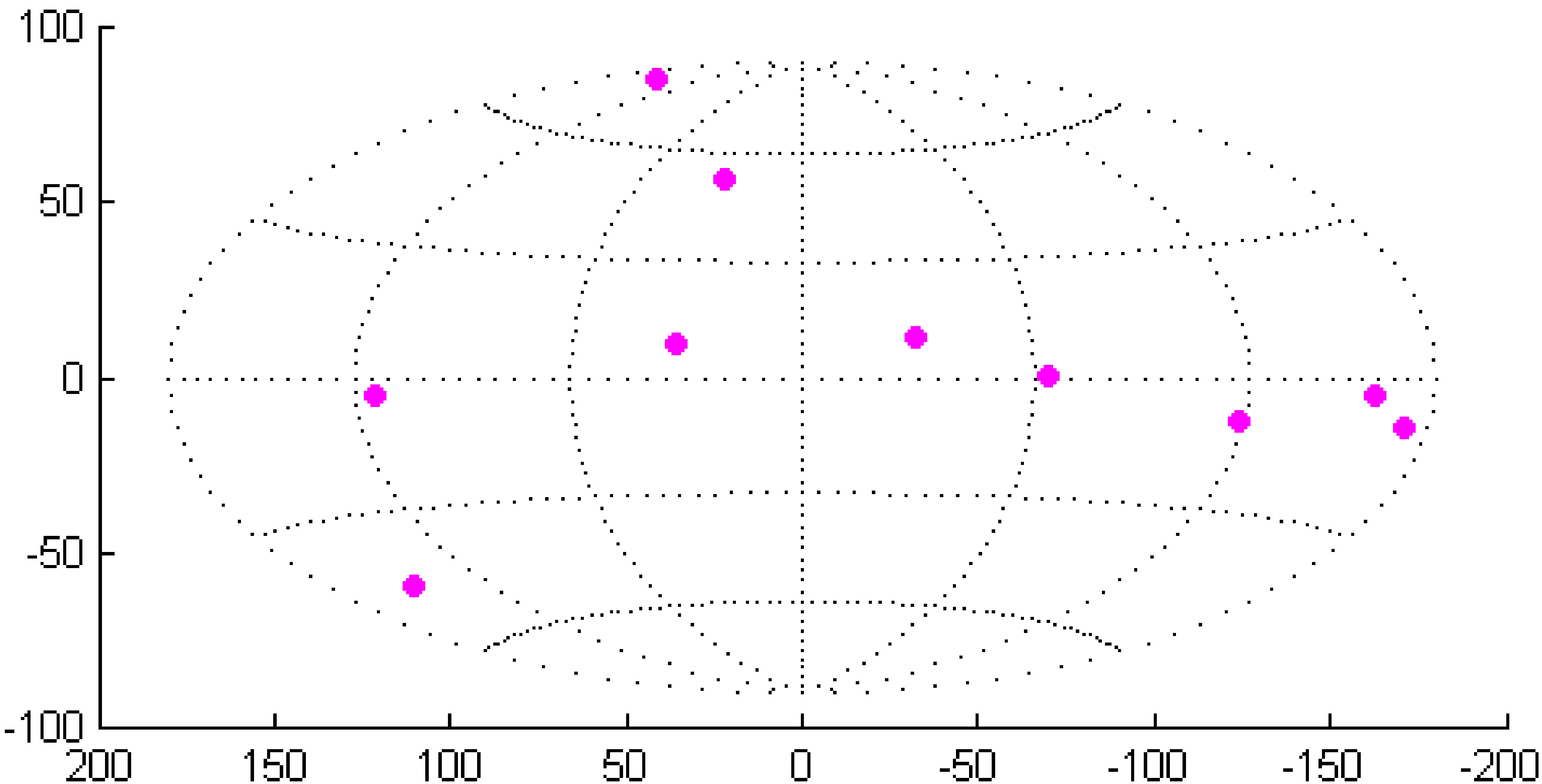


visible slot-gap pulsars



the total number of visible objects shown here must be scaled down by 0.6 to match the number of radio detections: ~ 29 objects are detectable by EGRET

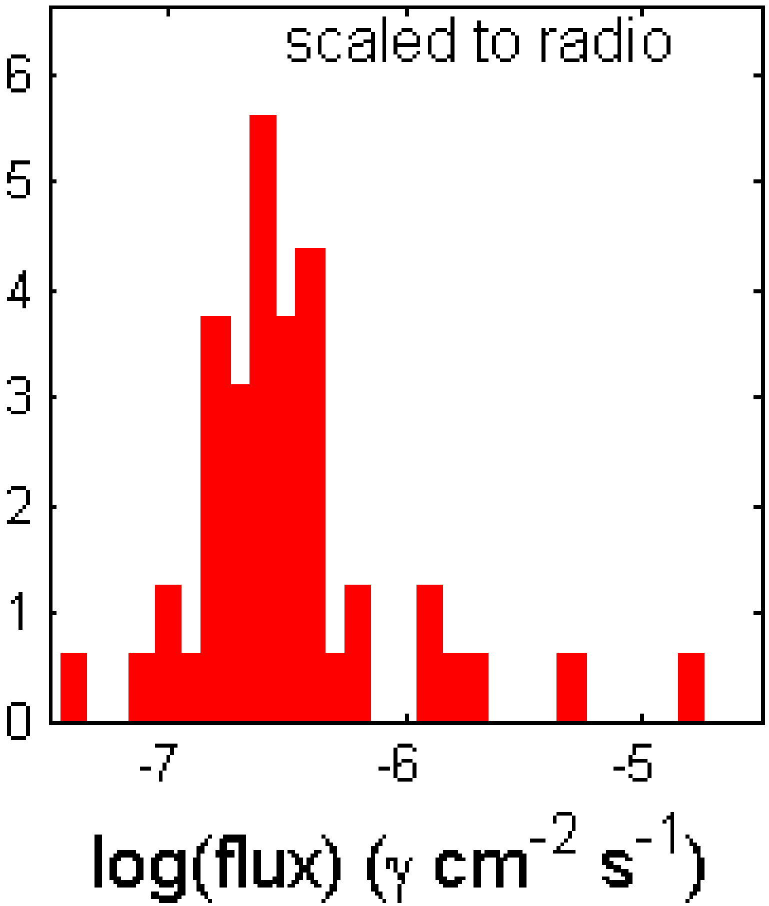
visible outer-gap pulsars

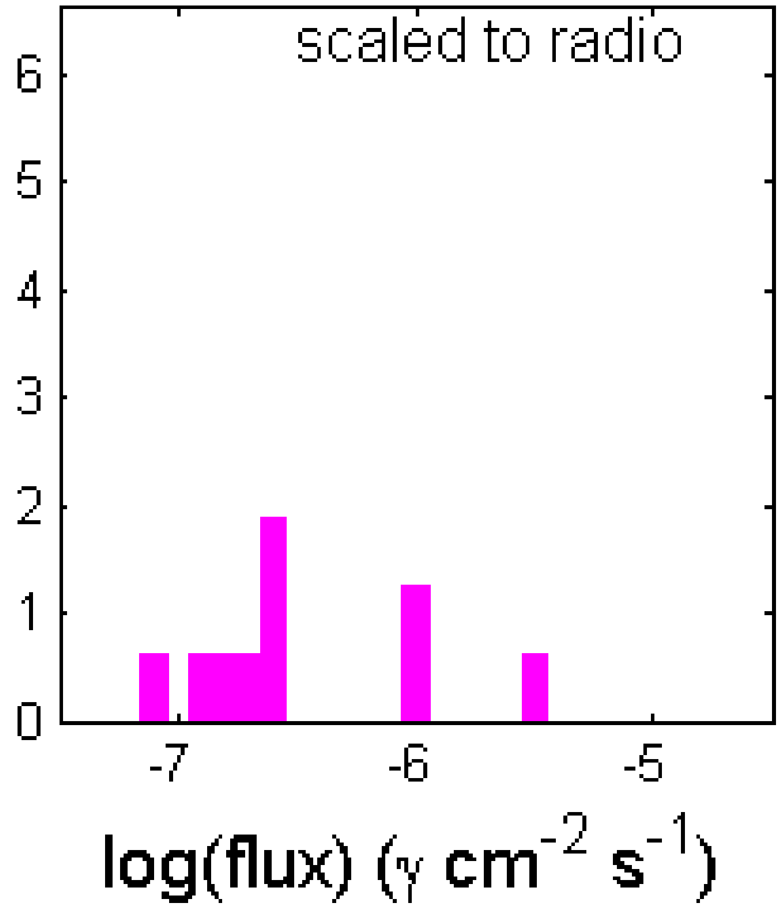


the total number of visible objects shown here must be scaled down by 0.6 to match the number of radio detections: ~ 6 objects are detectable by EGRET

visible γ-ray flux distributions

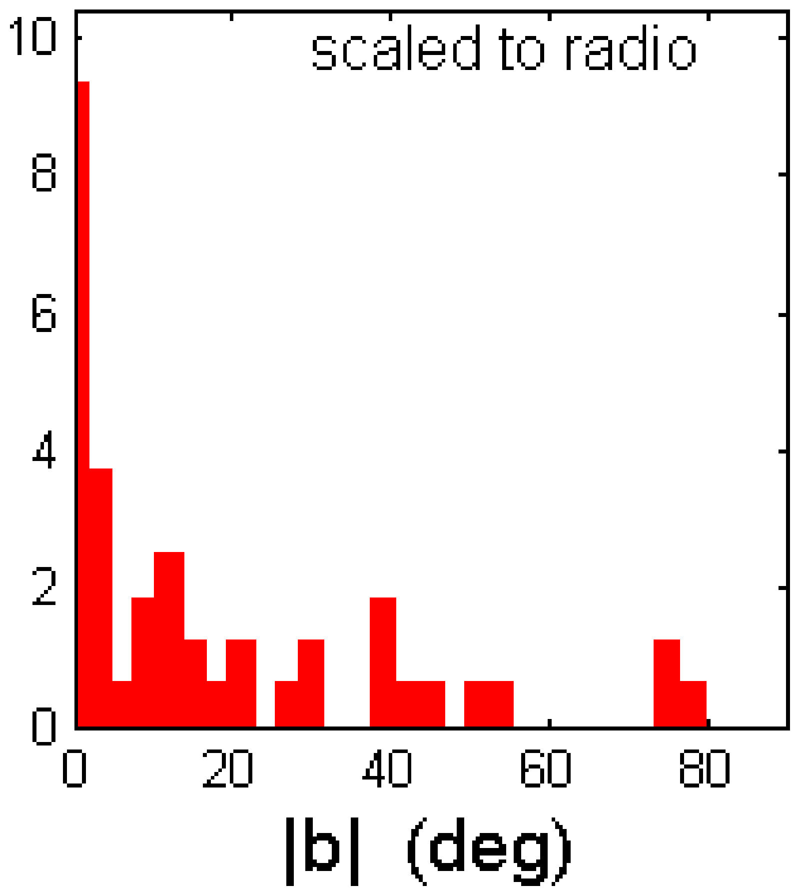
29.3 visible slot-gap pulsars   6.2 visible outer-gap pulsars

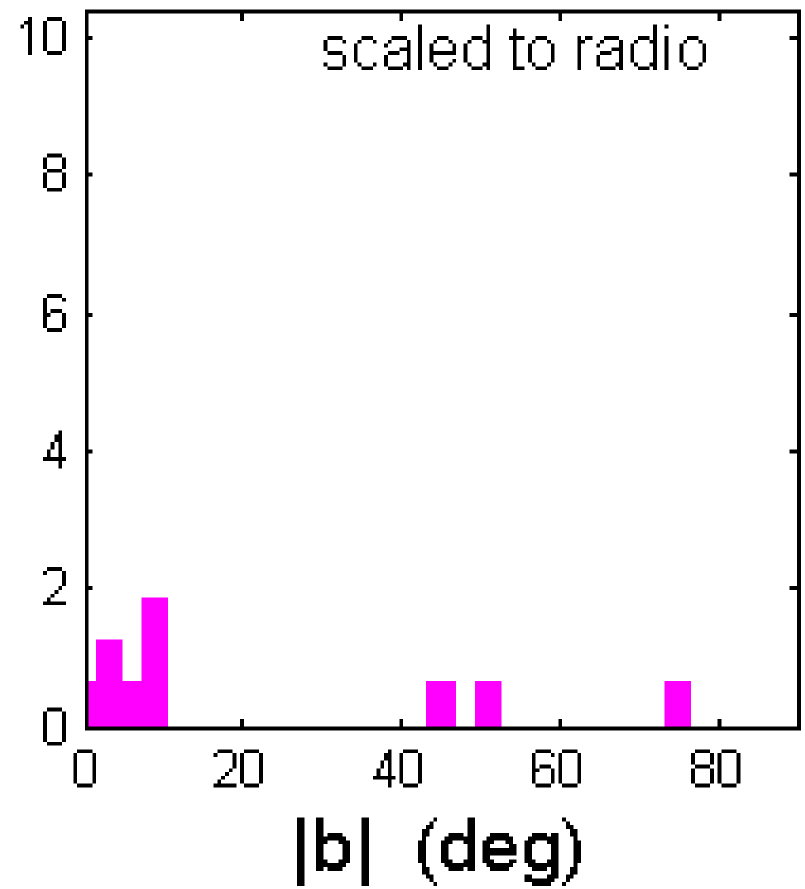




the flux histograms have been scaled to match the number of radio detections. The slot-gap distribution reasonably matches the fluxes spanned by both the unidentified and the known pulsed EGRET sources

latitude distributions





the latitude histograms have been scaled to match the number of radio detections. The slot-gap pulsars may significantly contribute to the unidentified EGRET sources up to 40° in latitude as well as close to the Galactic plane

Conclusions I

- slot-gap pulsars can match the space and flux distributions of the known γ-ray pulsars and of a large fraction of the unidentified EGRET sources.
  - ~ 30 are visible (for an $L_\gamma/\dot{E}$ efficiency of 10 %)
  - over a large range of $\dot{E}$: $5\ 10^{25} < \dot{E} < 2\ 10^{30}$ W
  - and ages: $0.02 < \tau < 3$ Myr
- in the present simple scenario, outer-gap pulsars appear to be fainter, therefore less are visible
  - even though they match the observed flux range
  - < 10 are visible
  - over a limited range of $\dot{E}$: $2\ 10^{26} < \dot{E} < 9\ 10^{27}$ W
  - and ages: $0.02 < \tau < 2$ Myr

Conclusions II

- flux estimates are extremely sensitive to the evolution of the beam geometry with age and to the radiative pattern inside the beam.
  - prescriptions are needed to check the behaviour of the outer-gap pulsars (the reduced beaming fraction for older thicker gaps may help to keep visible fluxes)
- the predicted γ-ray flux distributions peak well below the EGRET and GLAST sensitivities.
- the predicted flux distributions being very steep, a careful modelling of the non-uniform sensitivity of the γ-ray surveys is required to compare to the observations.

references

- Dyks & Rudak 2003,ApJ 598, 1201
- Gonthier, van Guilder, & Harding 2004, ApJ 604, 775
- Grenier, Casandjian, & Terrier 2005, Science 307, 1292
- Hobbs, Lorimer, Lyne, & Kramer 2005, MNRAS 360, 974
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- Zhang, Cheng, Jiang, & Leung 2004, ApJ 604, 317
- Zhang, Zhang, & Cheng 2000, A&A 357, 957