Fermi & the pulsars

Isabelle Grenier
Alice Harding
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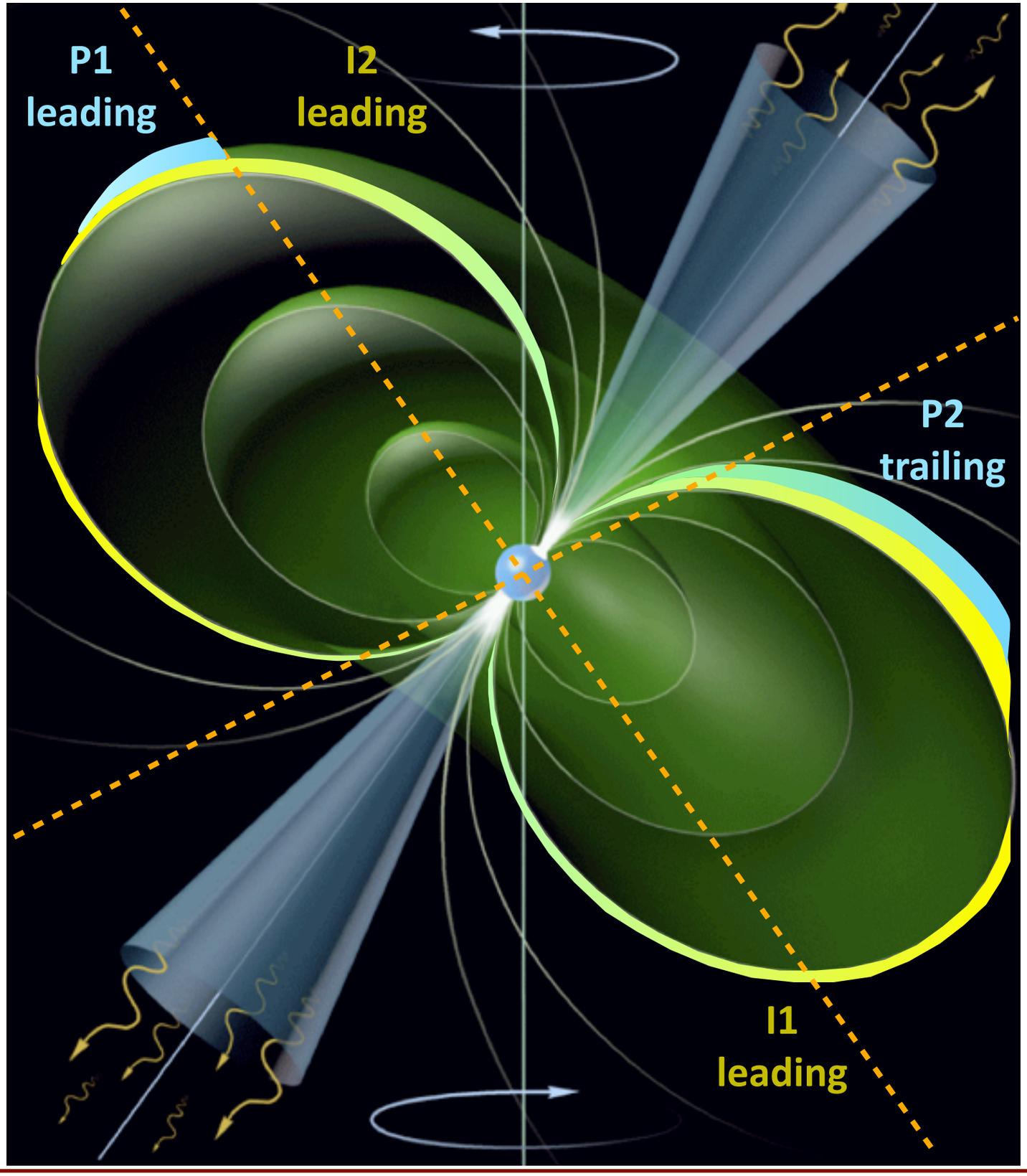
Aspen 2010

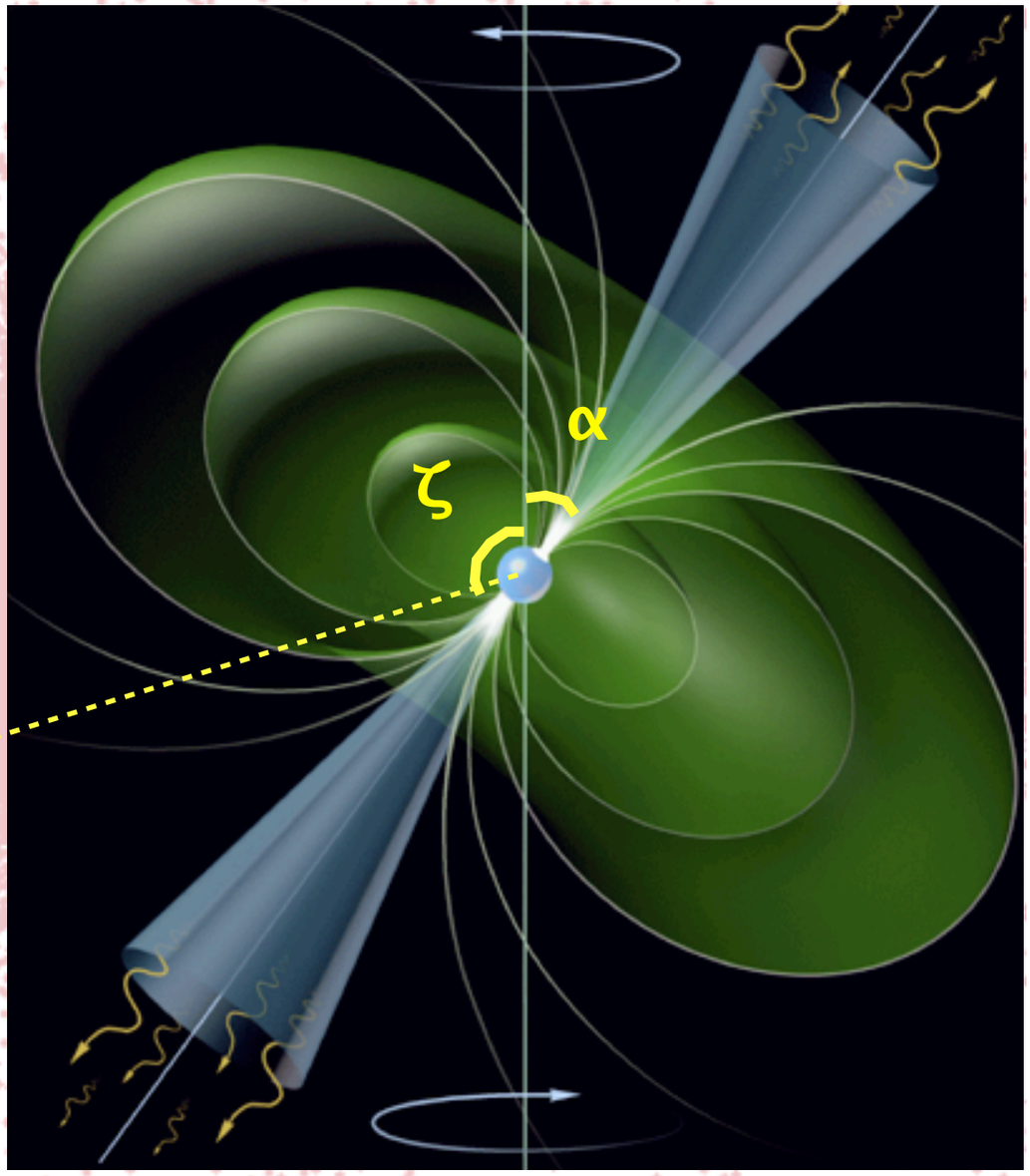
the gaps

… in our knowledge



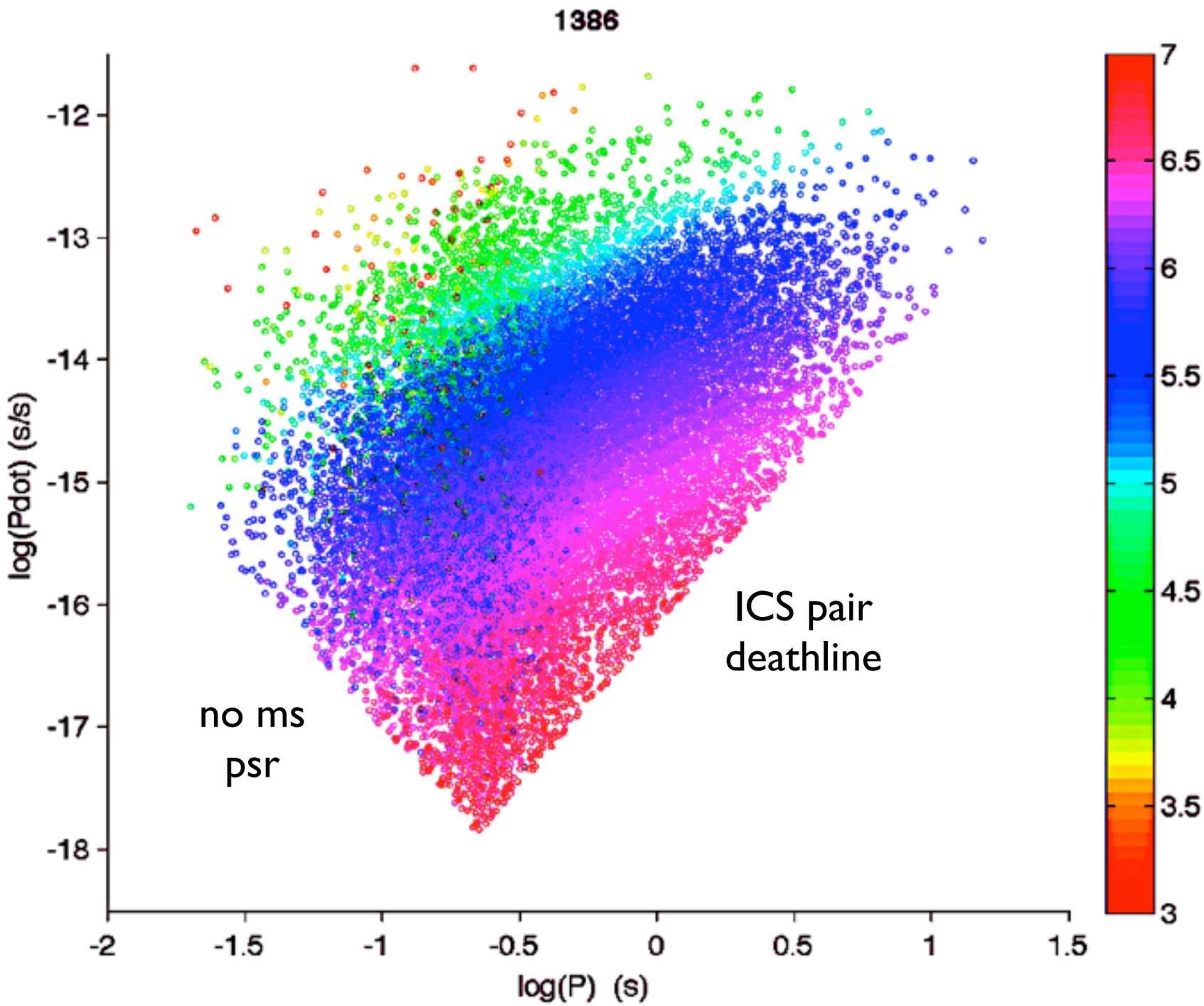
a recipe for neutron stars

- $R_* = 13$ km, $M = 1.5\ M_\odot$, $I_{mom} = 1.8\ 10^{38}$ kg.m^2
  I_{mom} from Lattimer & Prakash '07
- millions of NS in the Galactic potential
  constant birth rate over 1 Gyr
  velocity distribution (Hobbs et al. '05)
- birth period (gauss. distribution)
  - $\langle P_{birth} \rangle = 0.3$ s, $\sigma_P = 0.3$ s
- birth B field (2 gauss. distributions in log)
  - $\langle B \rangle = 10^{8.5}$ & 10^9 T, $\sigma_{logB} = 0.65$ & 0.8
  - $\tau_{Bdecay} = 2.8$ Myr or no decay
  - decay case today only
- random $0° < \alpha < 90°$ (little alignment < 1 Myr?)
  random $0° < \zeta < 180°$
- ICS death line for radio emission



after Gonthier et al. '09 arXiv:0912.3539

neutron star sample



a few spices


Aspen
Mastersof complications
Masters
of
complications
510

radio emission & visibility

- radio emission (Harding, Grenier, Gonthier '06)

  r ~ 0.05-0.3 R_{LC}

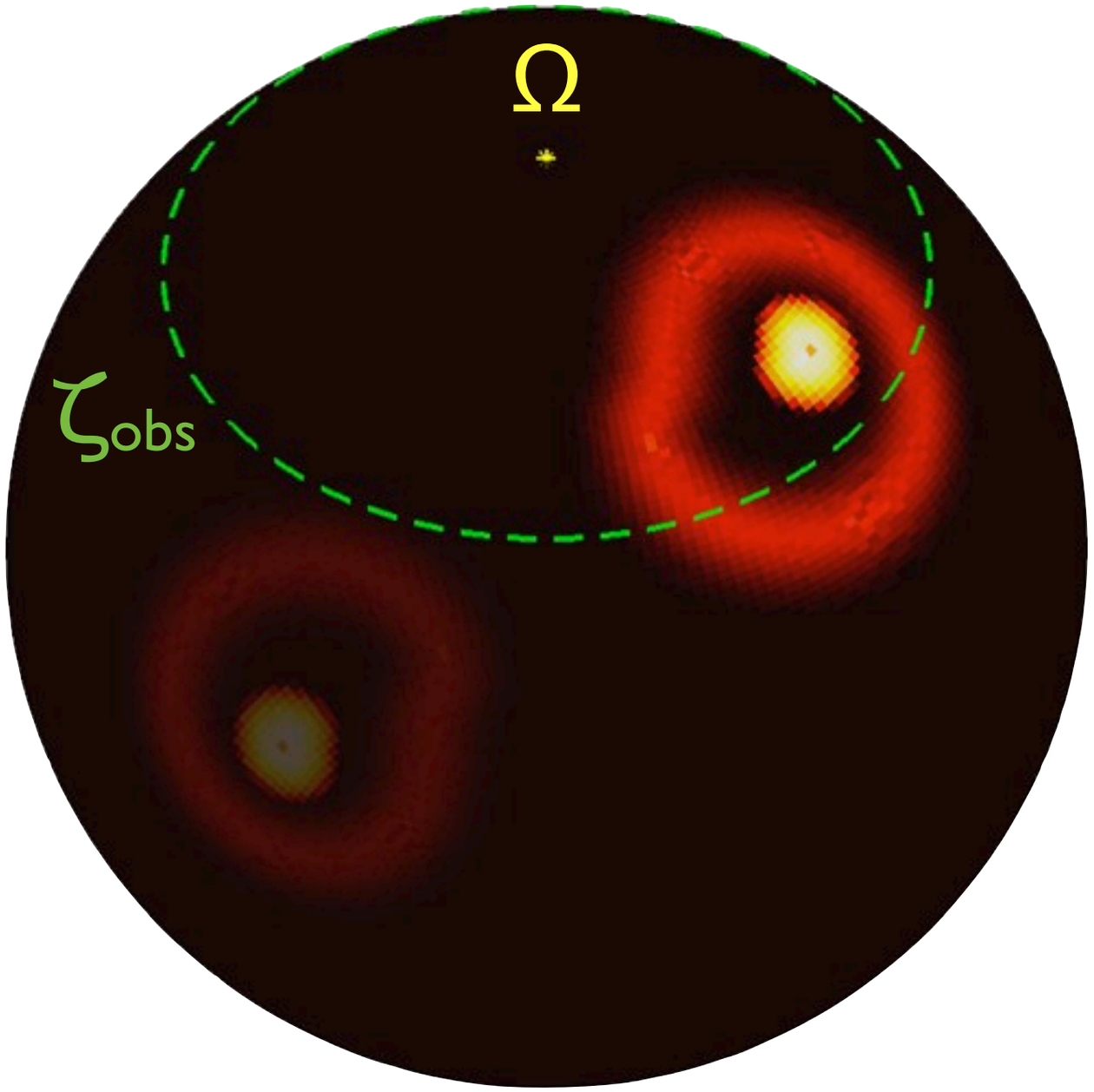
  narrow radio core + wider radio cone

  core/cone flux ratio

  total luminosity = f(P, Pdot)

  emission predicted at 0.4 and 1.4 GHz

  to compare with survey sensitivities



- ΣN(detectable radio pulsars) = ΣN(detected) in 10 radio surveys

slot-gap models

- low-altitude slot gap (Muslimov & Harding '03)

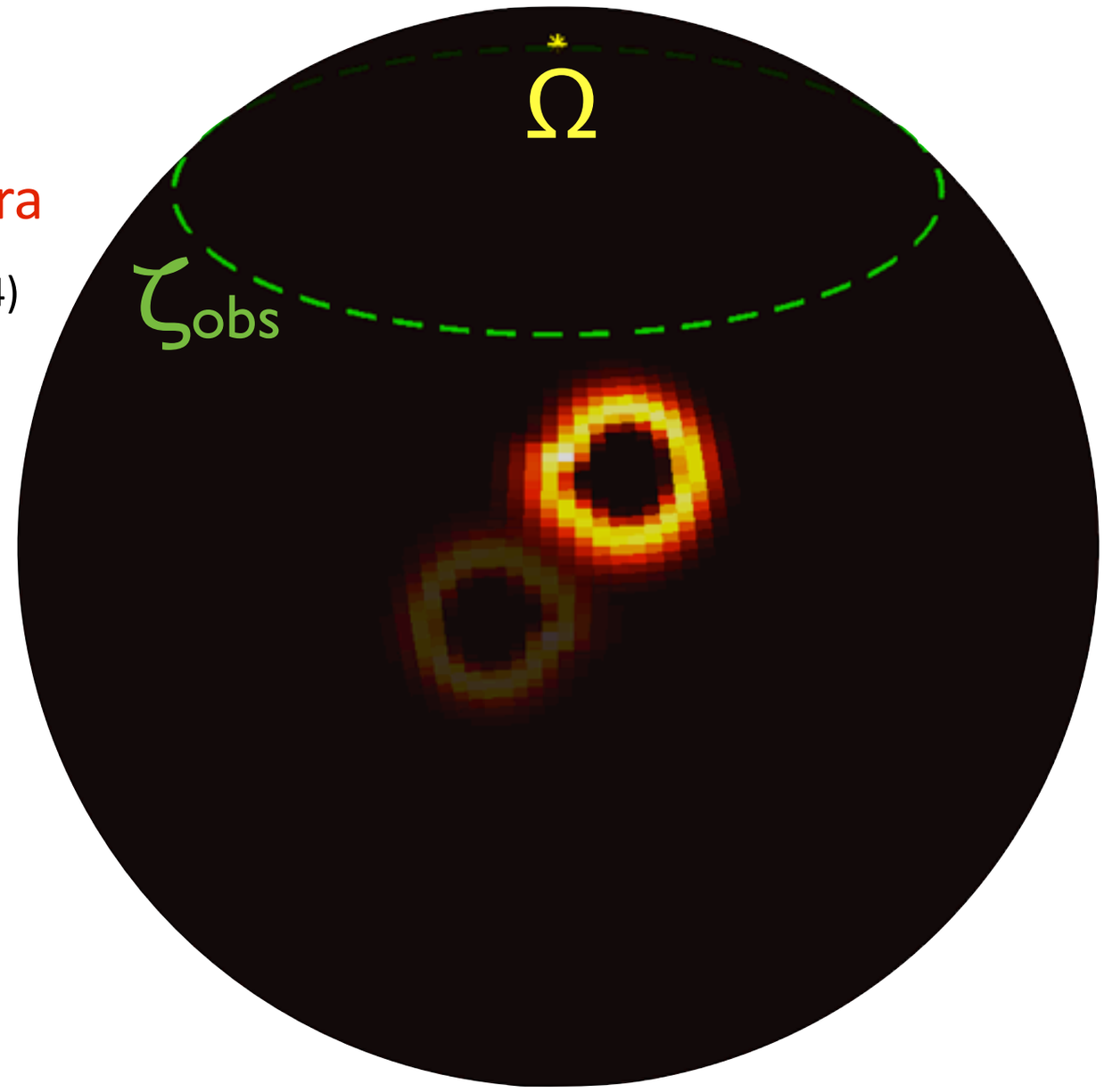
  $r \sim 4\ R_*$, $L_\gamma / L_{e\pm} \sim 1$

  but $\gamma + B \rightarrow e^\pm$ ruled out by Fermi spectra
- high-altitude slot gap (Muslimov & Harding '04)

  $r < 0.95\ R_{LC}$, $L_\gamma / L_{e\pm} > 1$
- gap width and profile $\Delta\xi = f(P, B, I_{mom})$

  $0.1 \leq \Delta\xi \leq 0.5$

  photon distribution inside gap as $\Phi(\xi_*)$



$$L_{\gamma(\mathrm{PC\ or\ SG})} \propto \Delta\xi^3\ \dot{E}_{psr}$$

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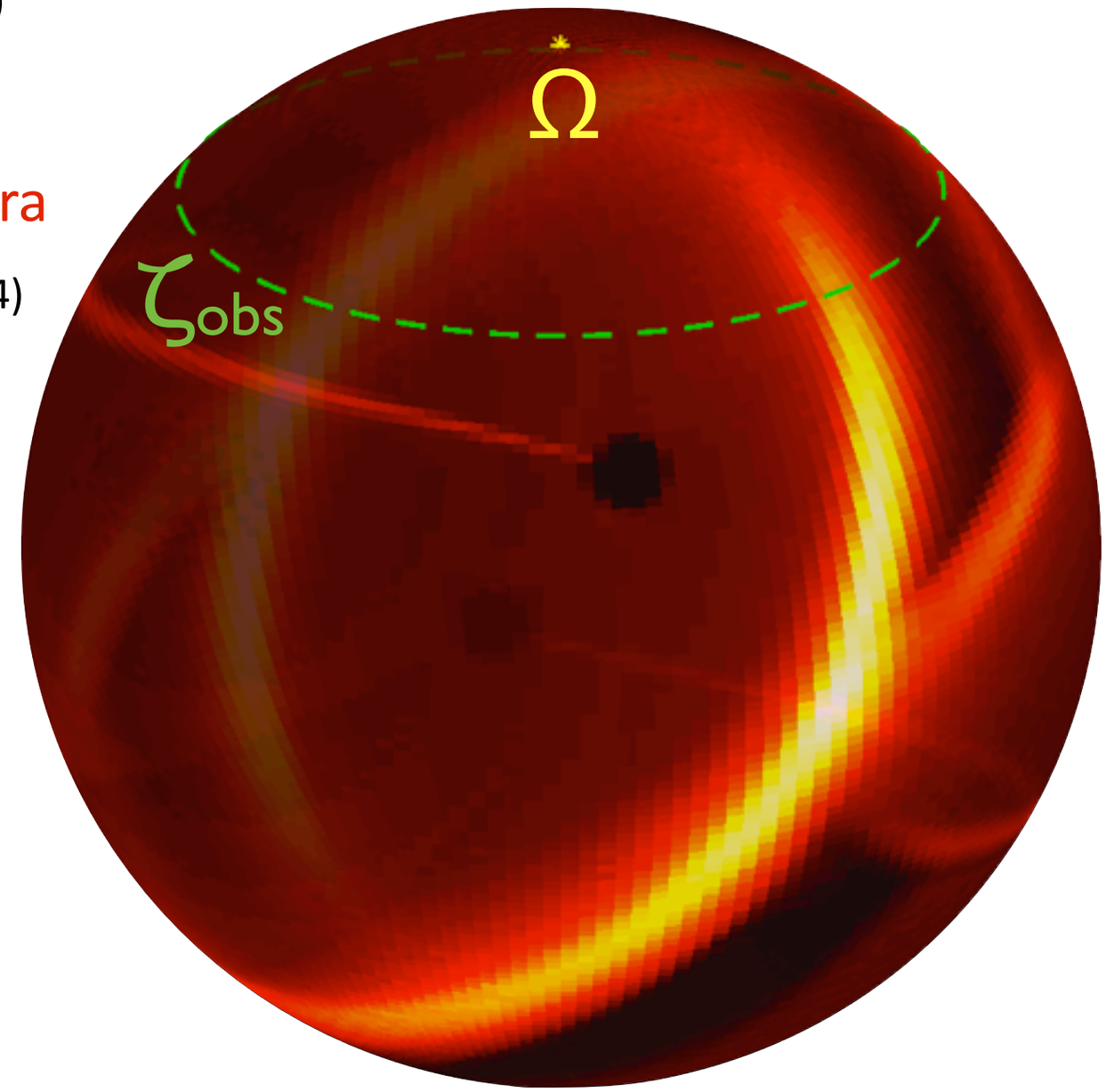

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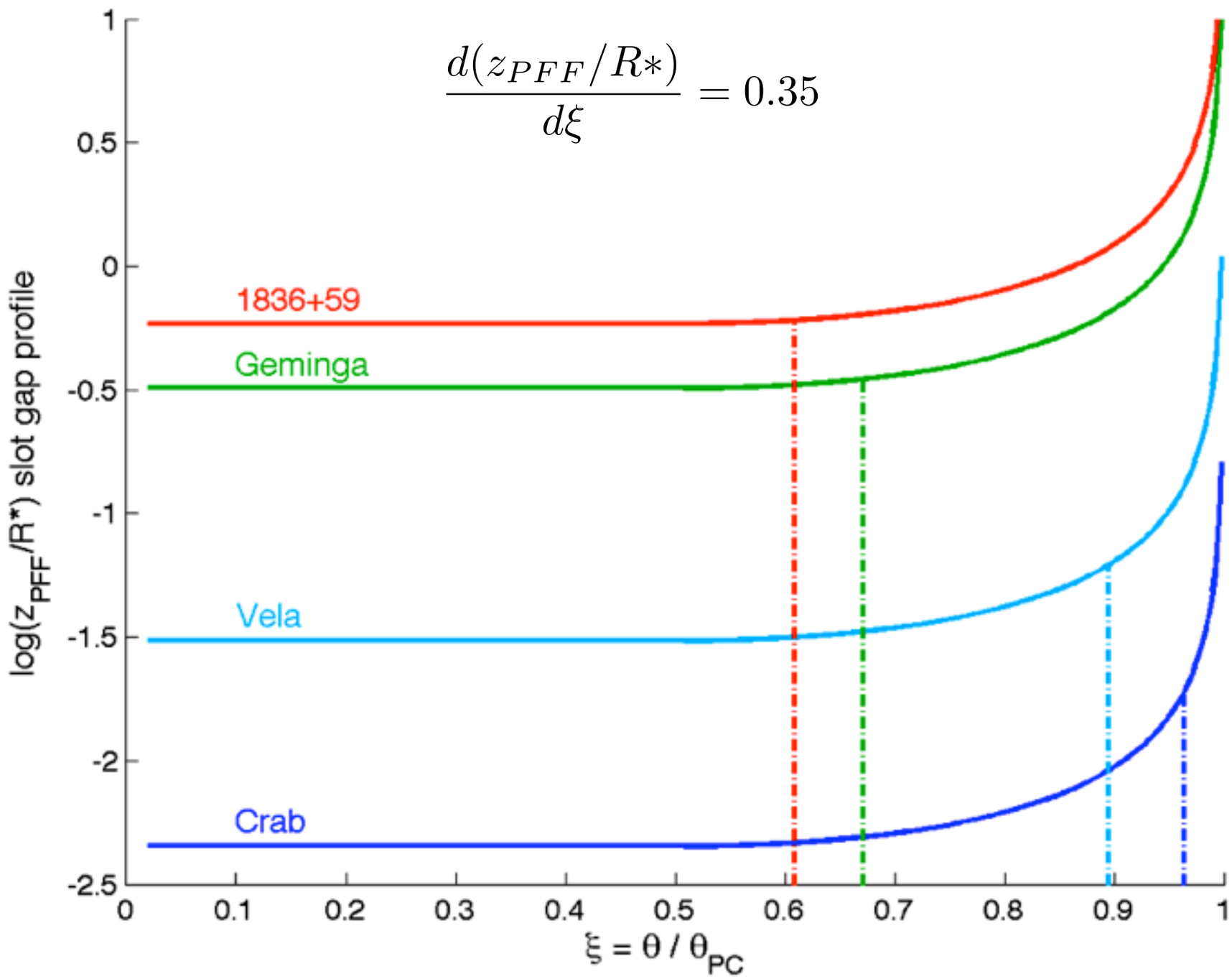
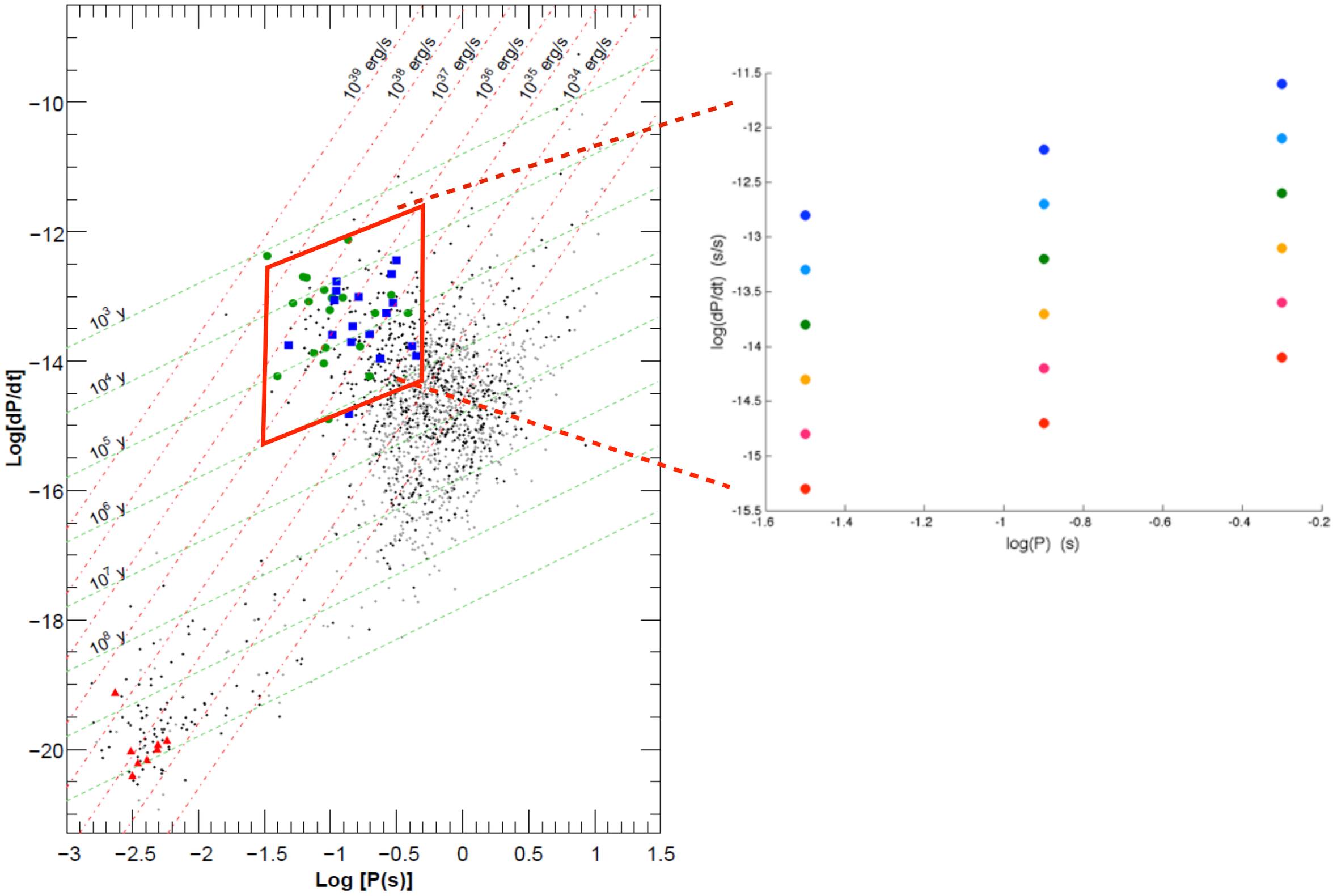
the slot gap evolution

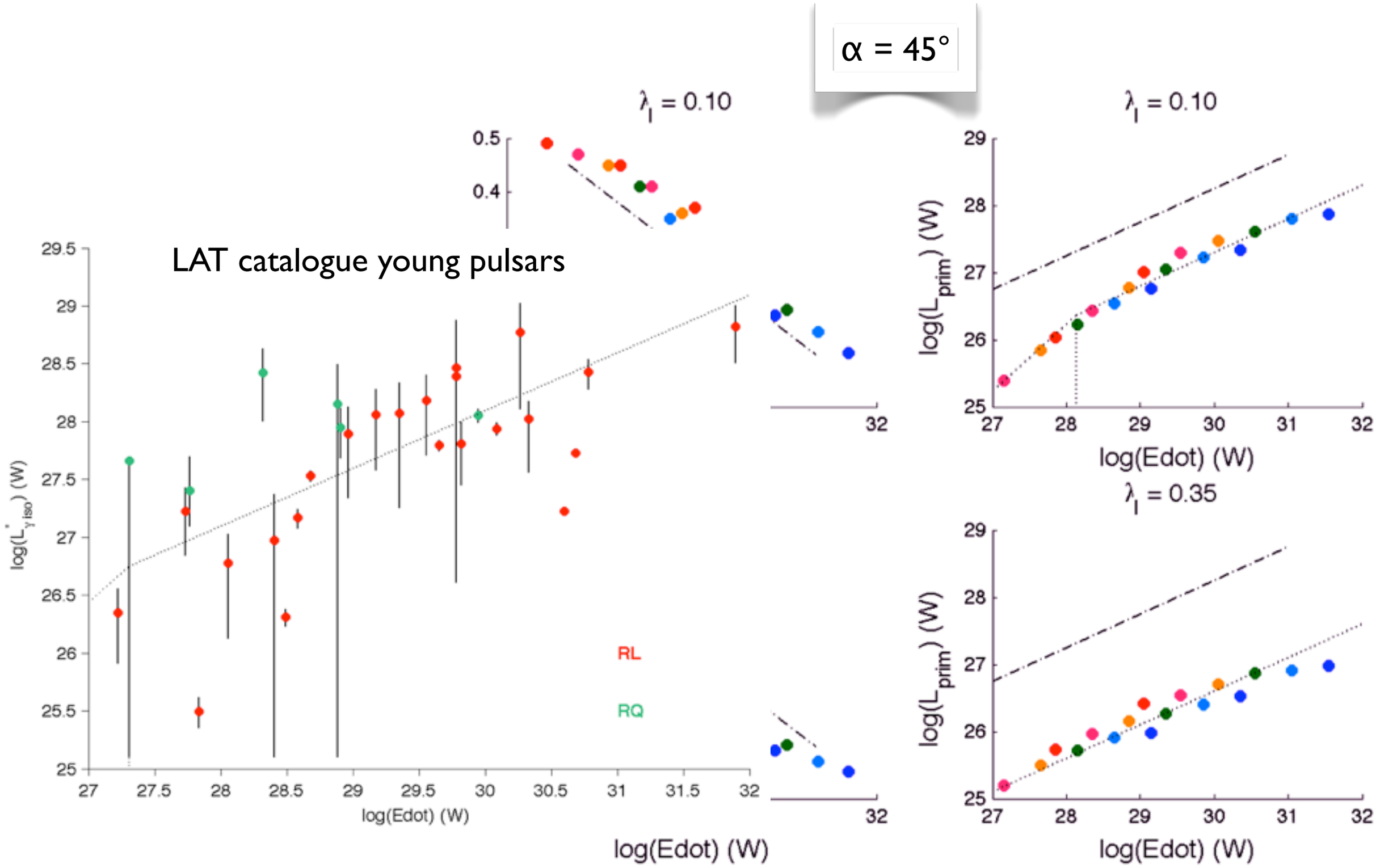
- higher and wider with old age



sample stars



SG width and luminosity evolution



outer-gap models

- outer-gap width $w_{OG} \perp$ B lines (Zhang et al. '04)

  calculated for each star using the full return current to heat up the polar cap

  $\gamma_{\text{along last line}}$ at r_{avg} from curvature radiation (reaction limited)

  PFF where $\tau(\gamma_{\text{along last line,ravg}} + X \rightarrow e^{\pm}) = 1$

  $R_{null} < r < 0.95\ R_{LC}$, $L_{\gamma} / L_{e\pm} \leq 1$

  $w_{OG} < 0.7$

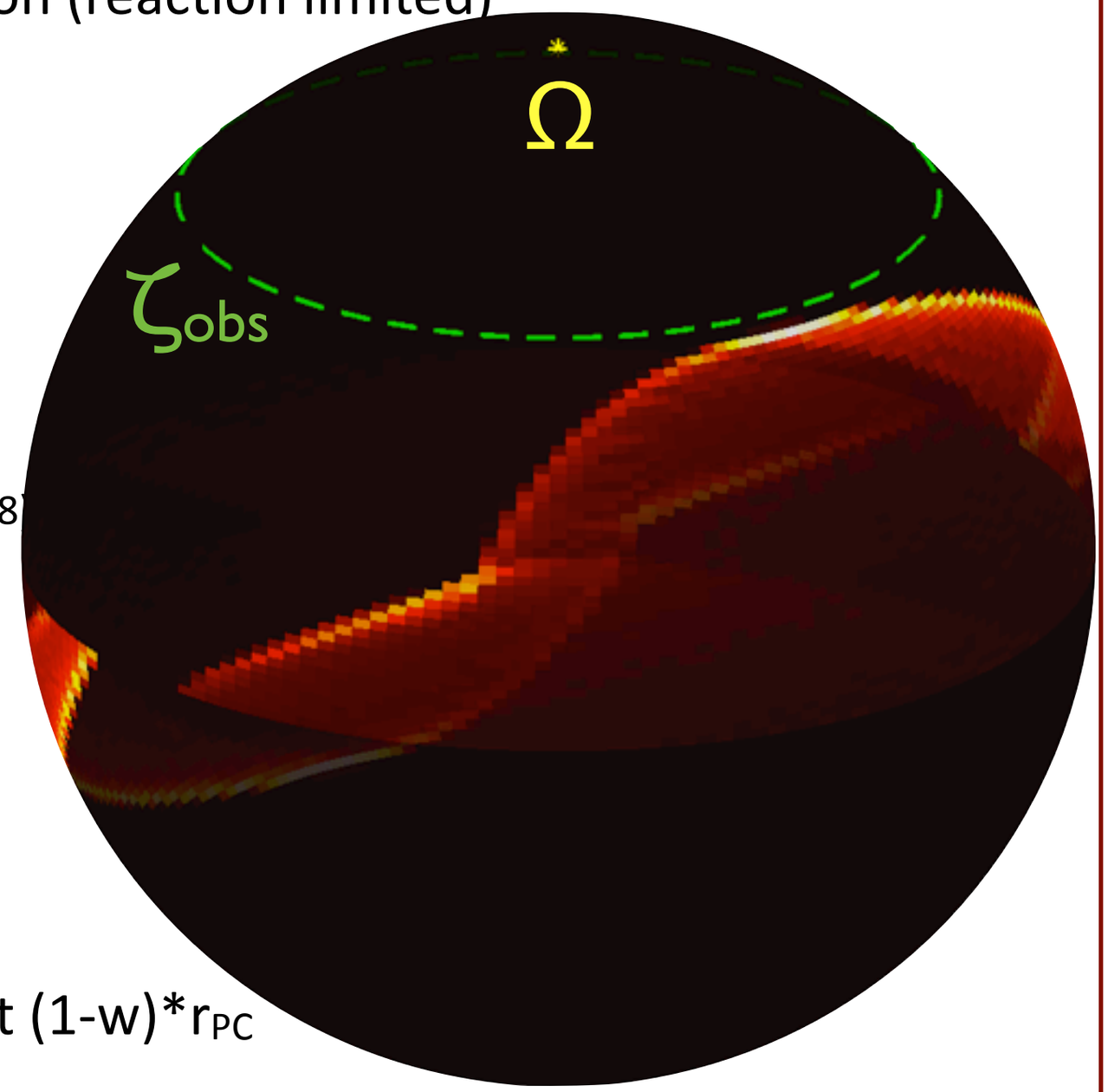
  $$L_{OG} \propto w_{OG}^3\ \dot{E}_{psr}$$

- One-pole caustic outer-gap (Watters et al. '08)

  $w_{OPC} = (10^{26} W/\dot{E}_{psr})^{1/2}$

  $w_{OPC} < 0.7$

  $$L_{OPC} \propto w_{OPC}\ \dot{E}_{psr}\ ?$$

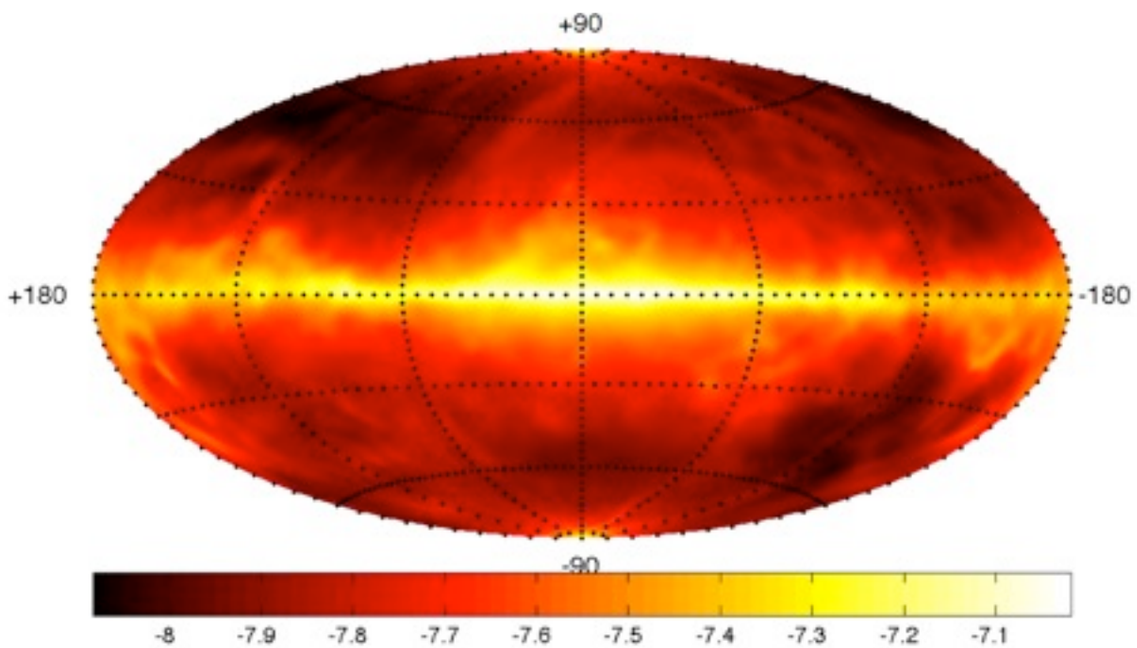


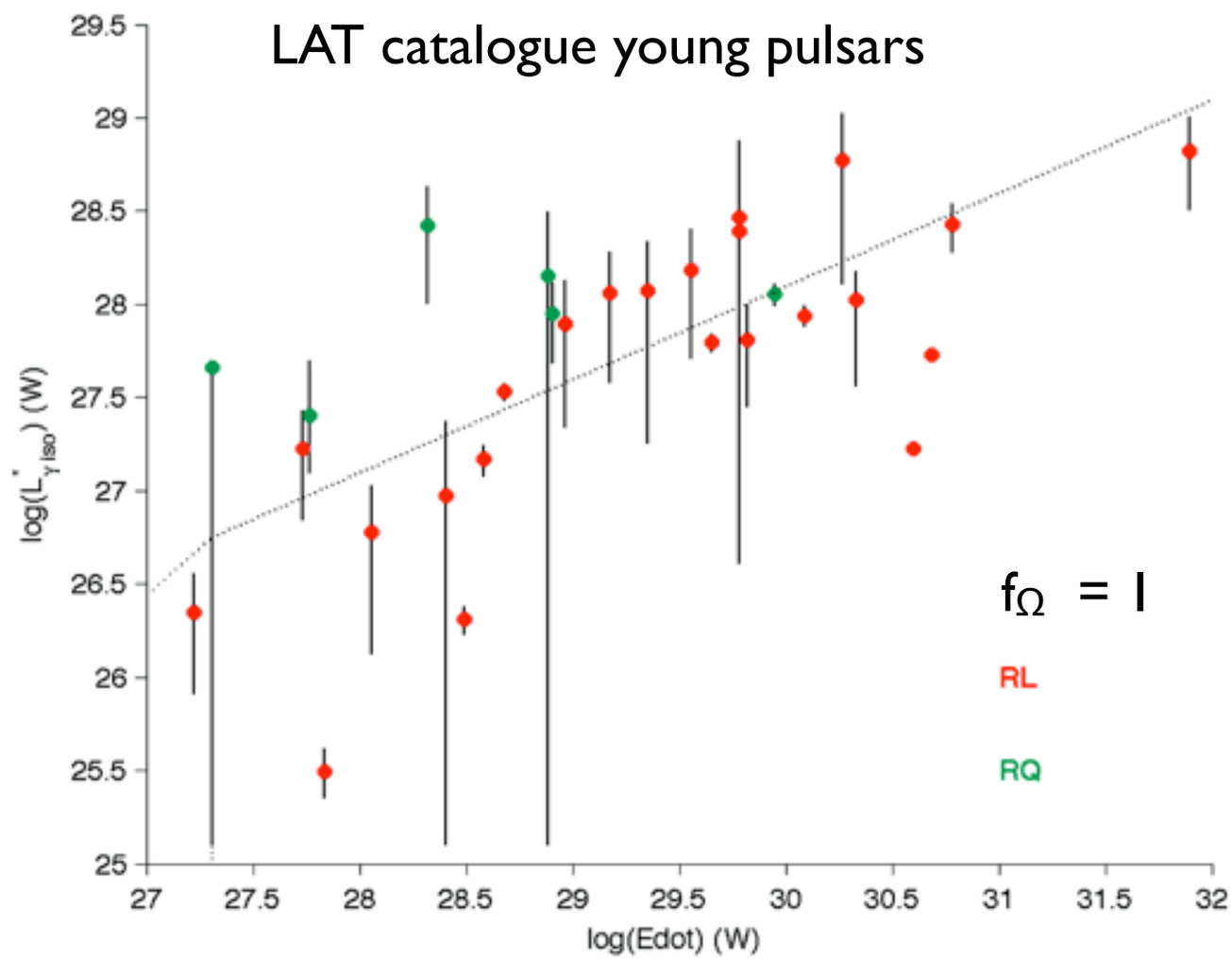
thin emitting layer at upper boundary at $(1-w)*r_{PC}$

no emission at any ζ for small α

visible pulsars

- L_γ/L_e radiative efficiency to match the LAT pulsar catalogue luminosity data
- simulated photon flux (E > 100 MeV) above the non-uniform sensitivity threshold



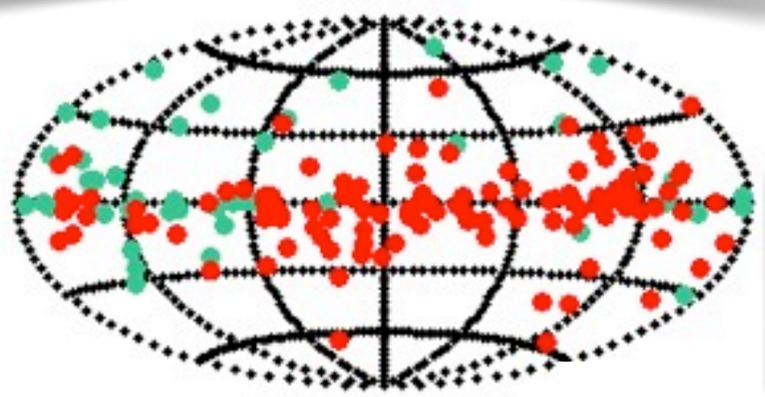


catalog: arxiv:0910.1608
Abdo et al. '10, ApJS, 187, 460

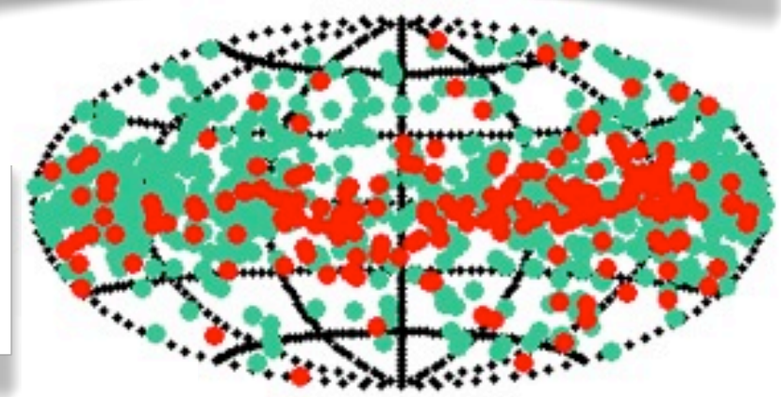
visible pulsars

- L_γ/L_e radiative efficiency to match the data (PC = 1, SG = 2.5, OG = 0.4, OPC = 0.2)

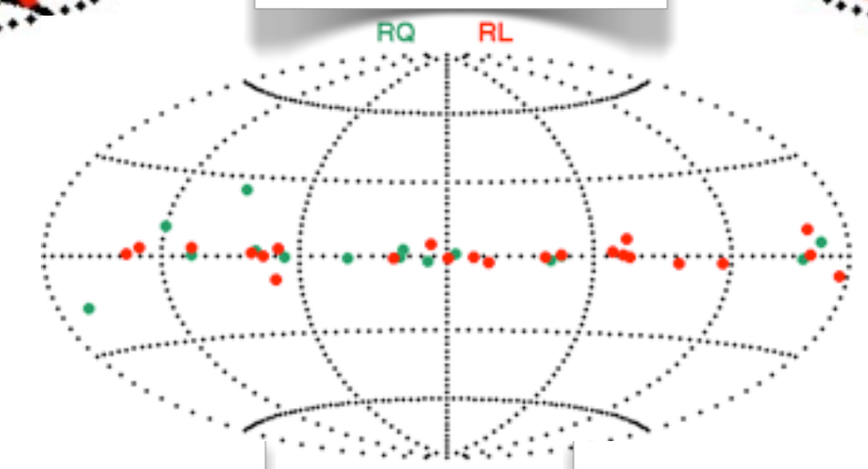
PC = 8 psr, RL/RQ = 2



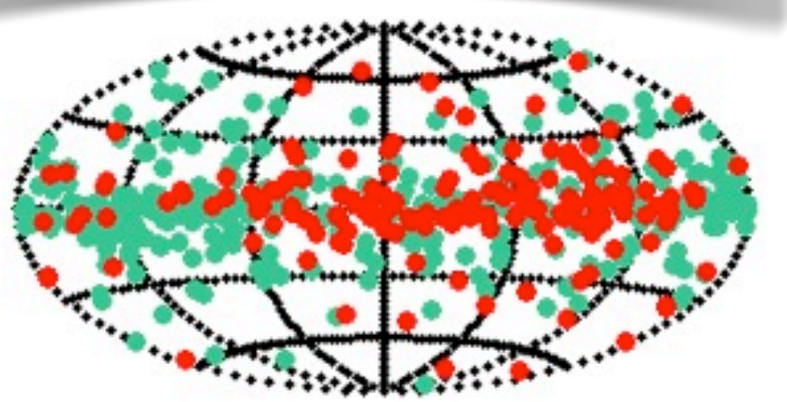
SG = 40 psr, RL/RQ = 0.3



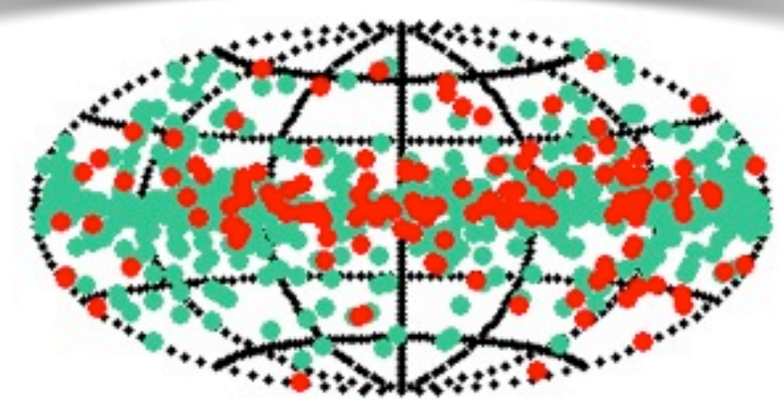
LAT 38 psr
RL/RQ = 1.5



OG = 24 psr, RL/RQ = 0.5

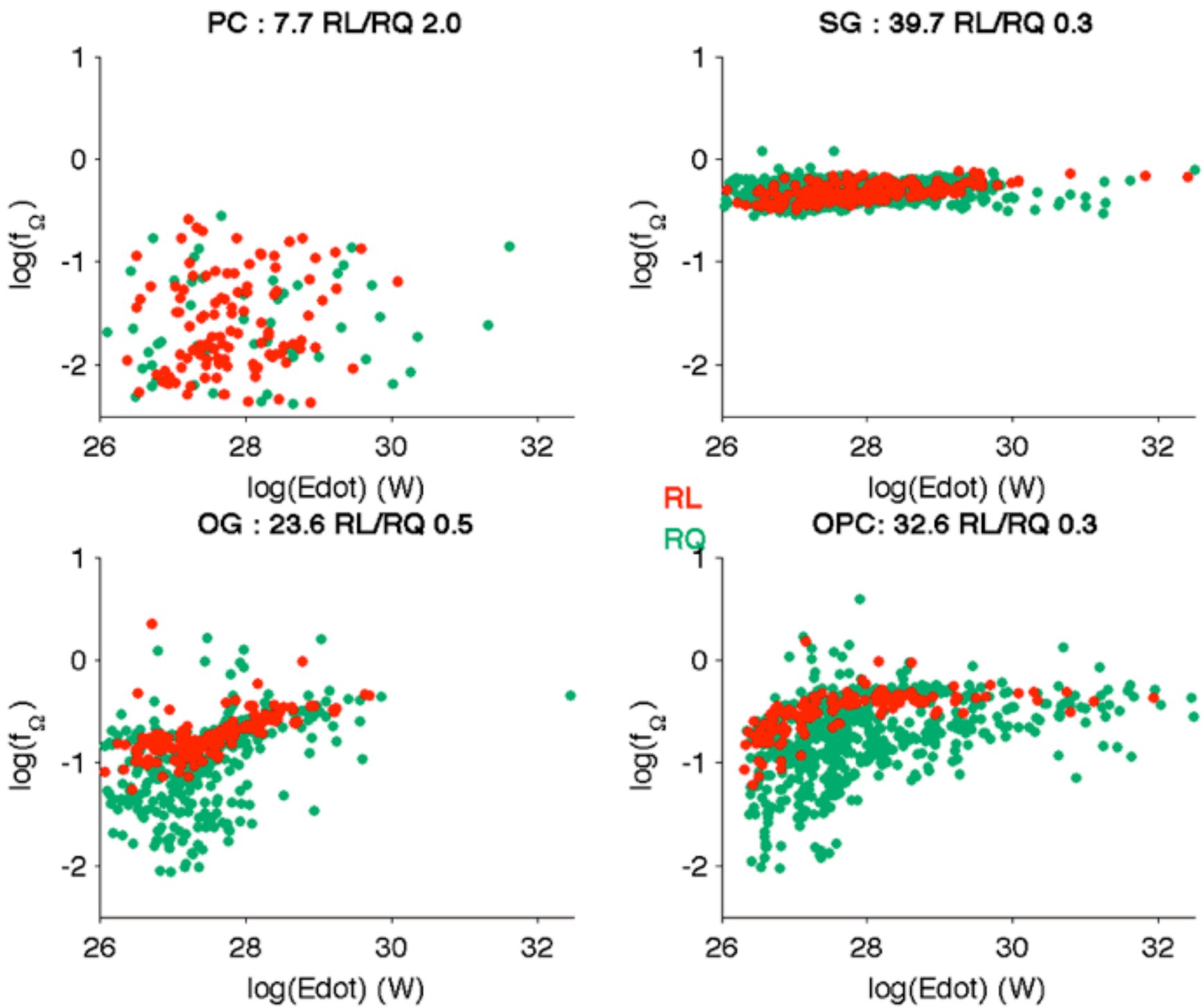


OPC = 33 psr, RL/RQ = 0.3



beaming fractions f_Ω

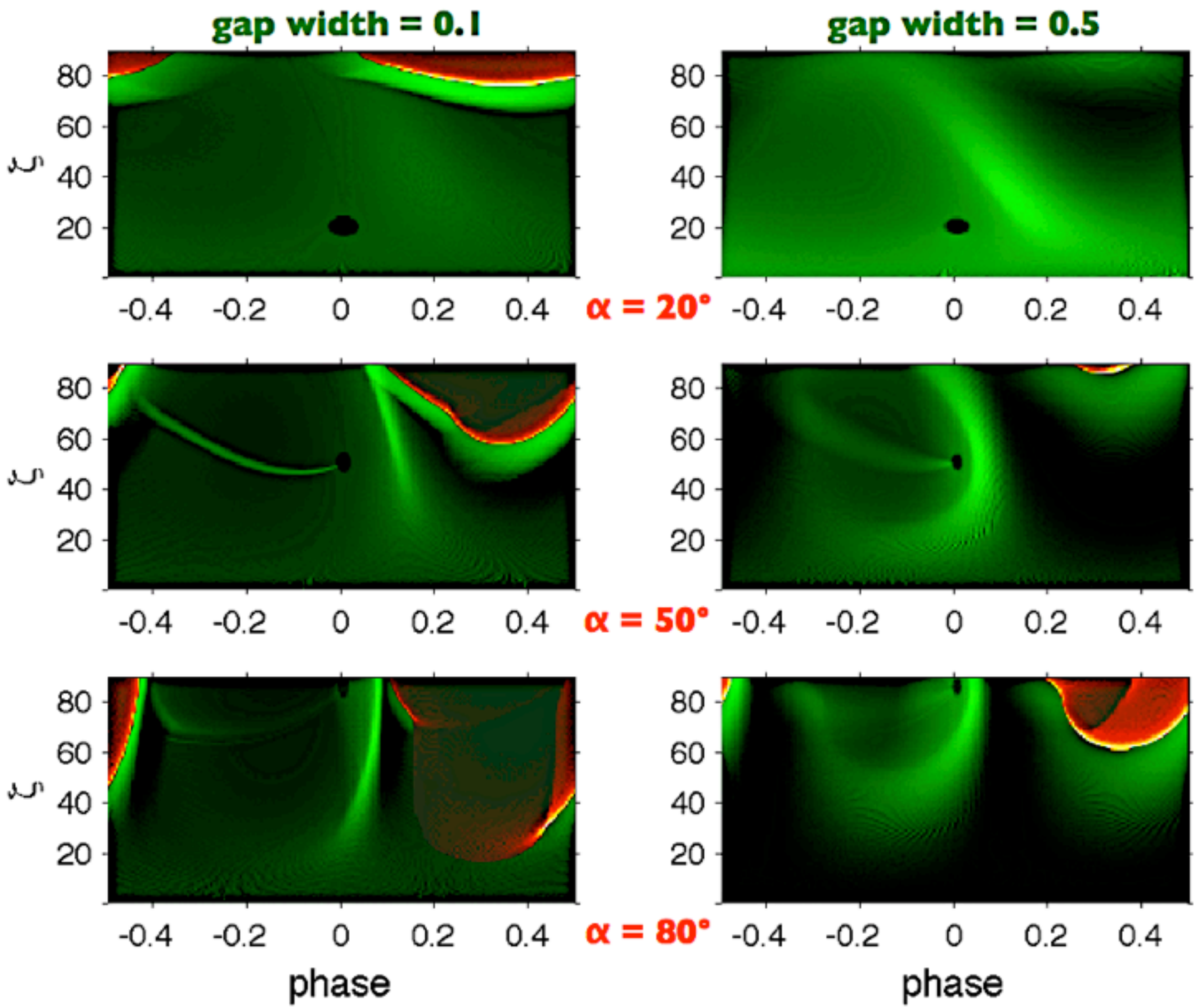
- RL: modest evolution with age



$f_\Omega \sim 0.58$
$f_\Omega \sim 0.49$

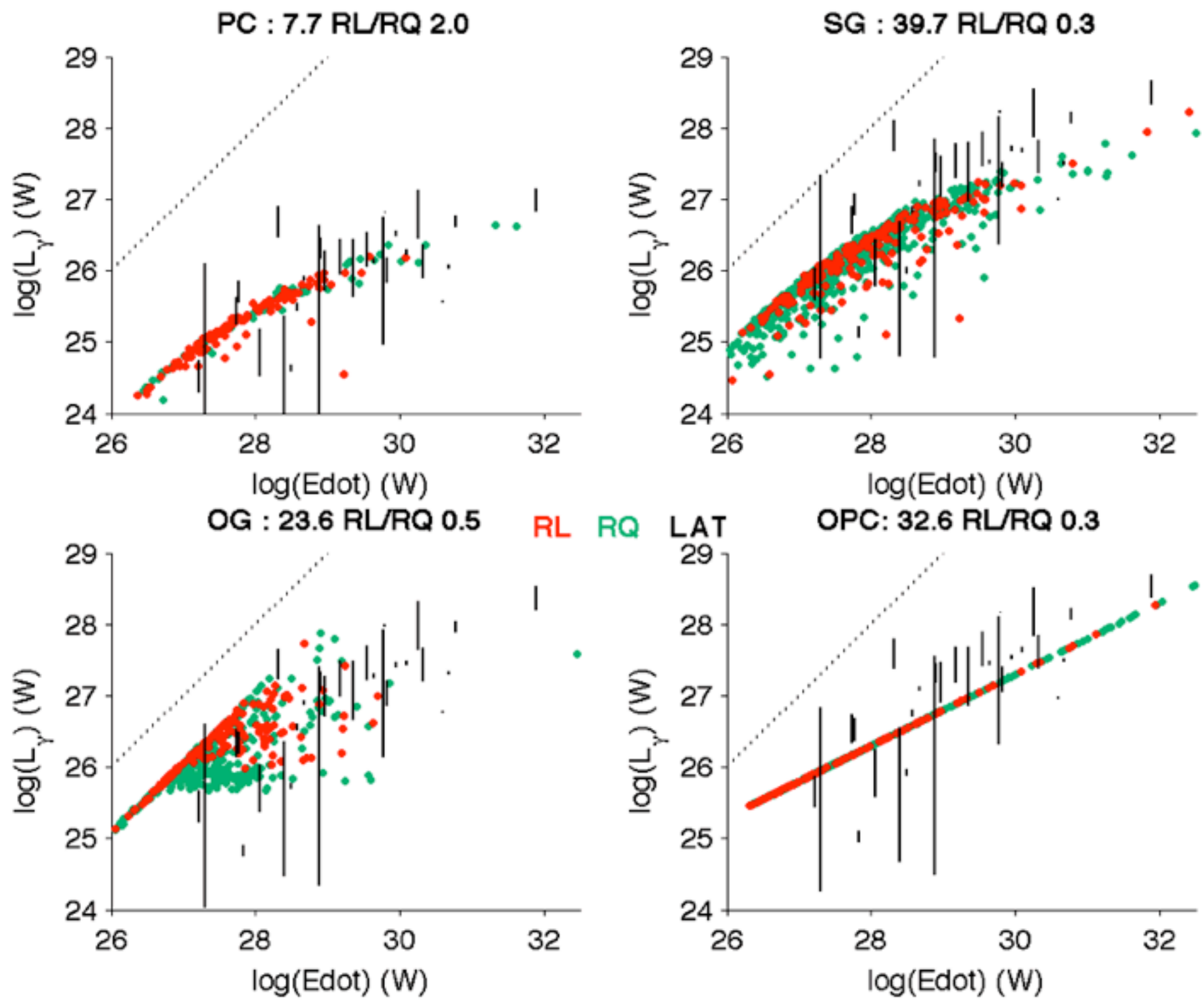
$f_\Omega \sim 0.43$
$f_\Omega << 0.31$

SG & OG phaseplots



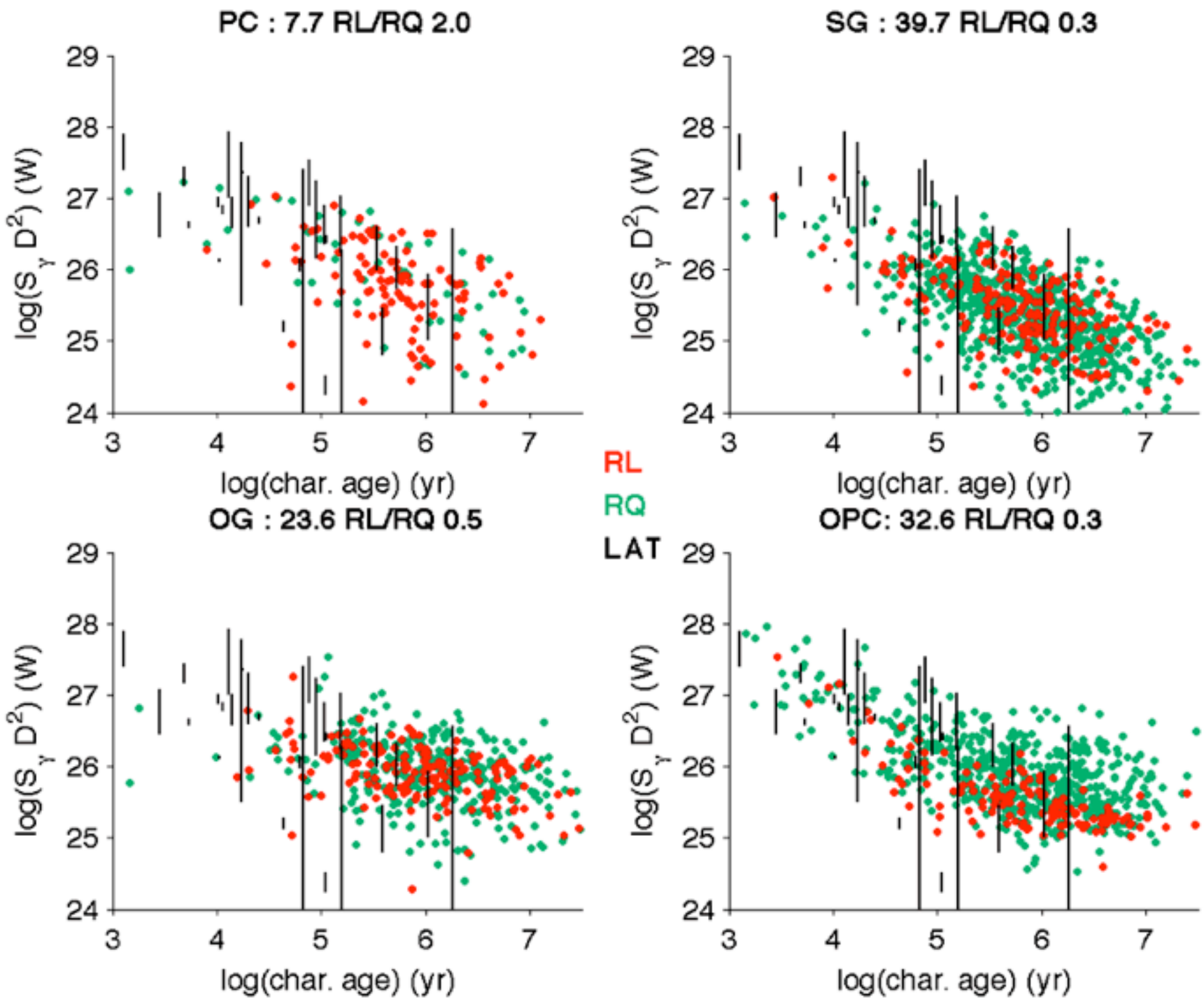
intrinsic luminosities

- f_Ω (age) for LAT psr
- all models:
  lack of $10^{3\text{-}4}$ yr psr
- OG-OPC: too few visible pulsars
- SG: requires super GJ current in the gap

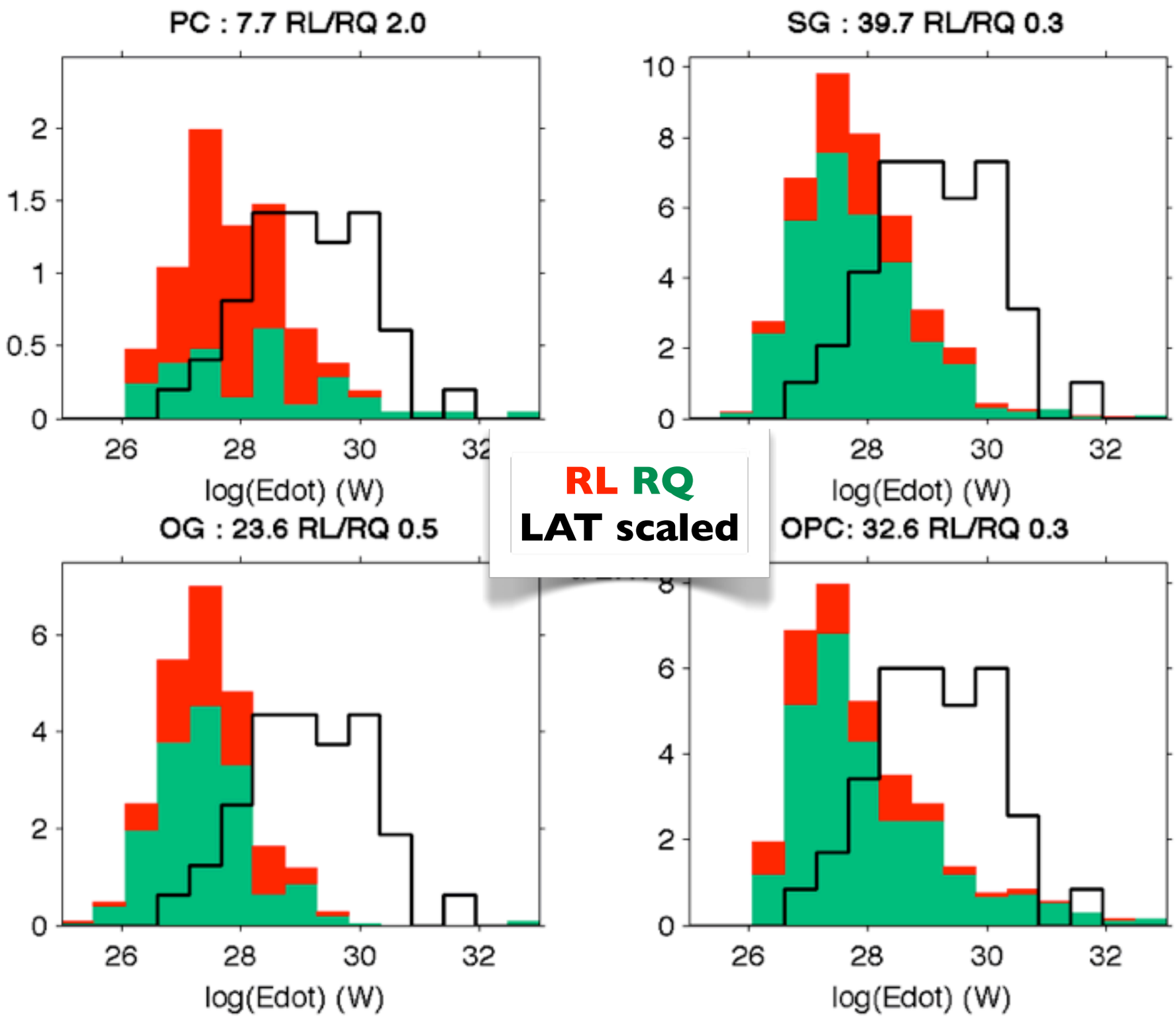


brightness evolution

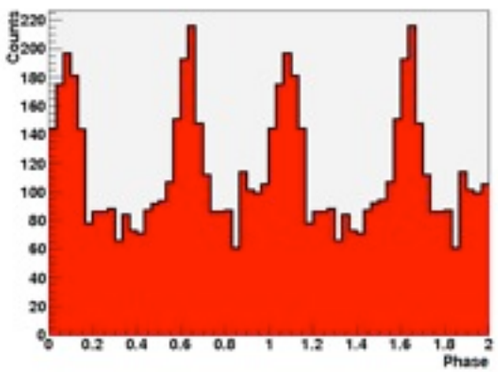
- only observed quantities



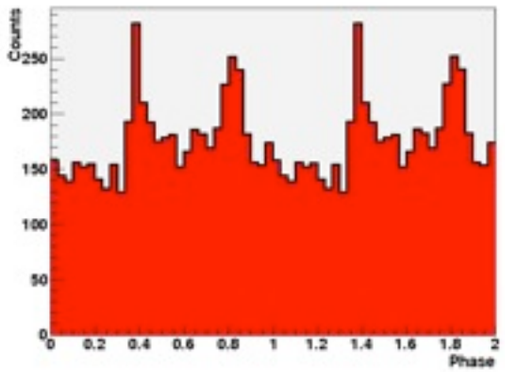
too few 10-kyr old pulsars



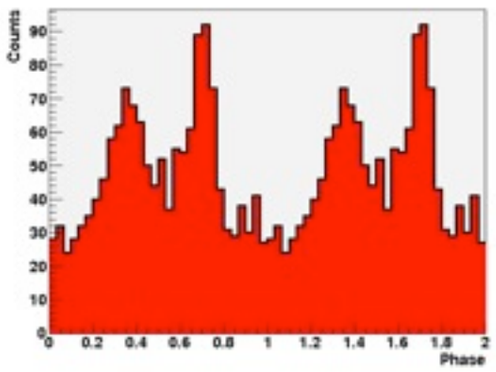
lightcurve morphologies



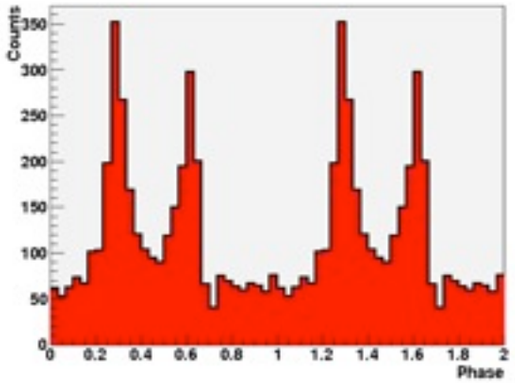
3EG J1826-1302 (Eel)



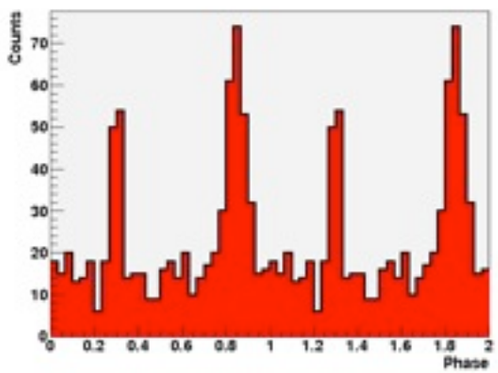
3EG J1420-6038 (Rabbit)



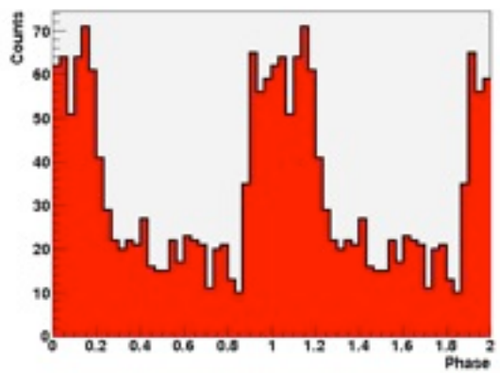
3EG J1734-3232



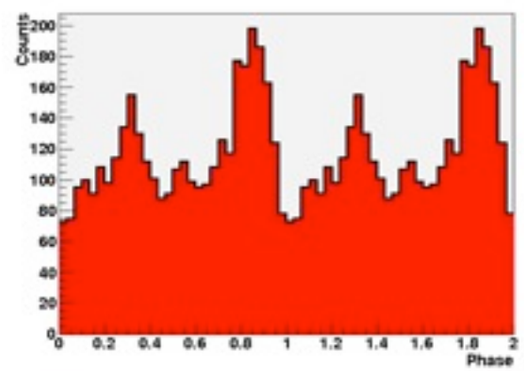
3EG1809.5 (Taz)



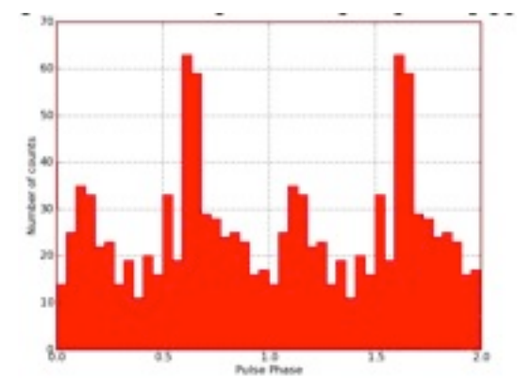
3EG J0631+0642



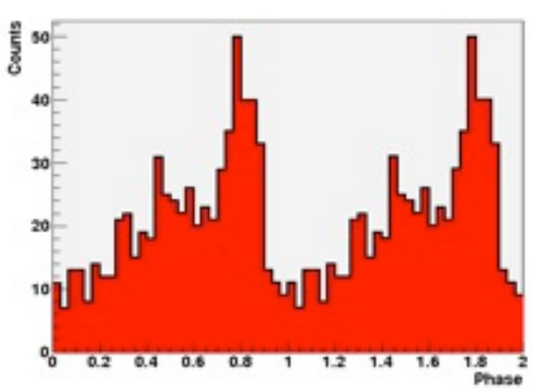
3EG J1741-2050



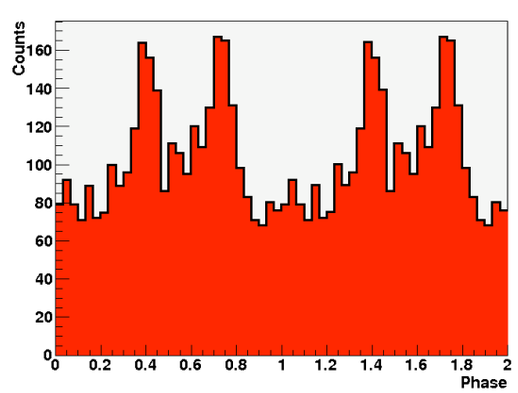
3EGJ2020 γ Cyg



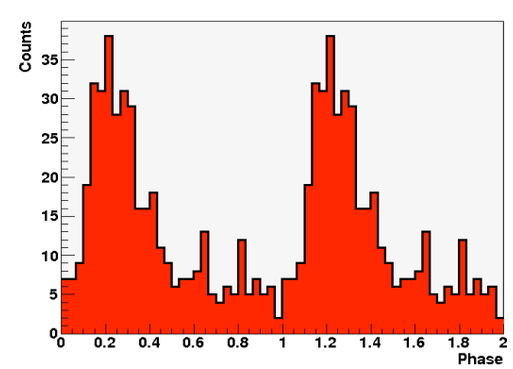
3EG J2033+4118



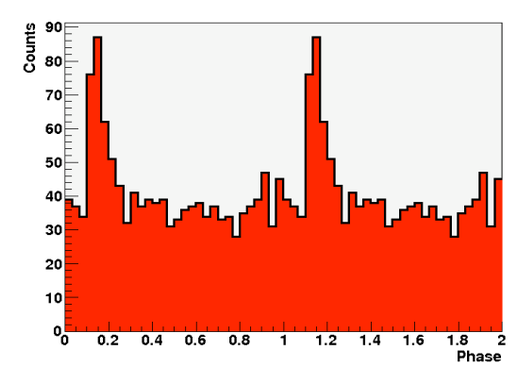
3EG J1958+2909



MGRO J1908+06



new Fermi J0357+32

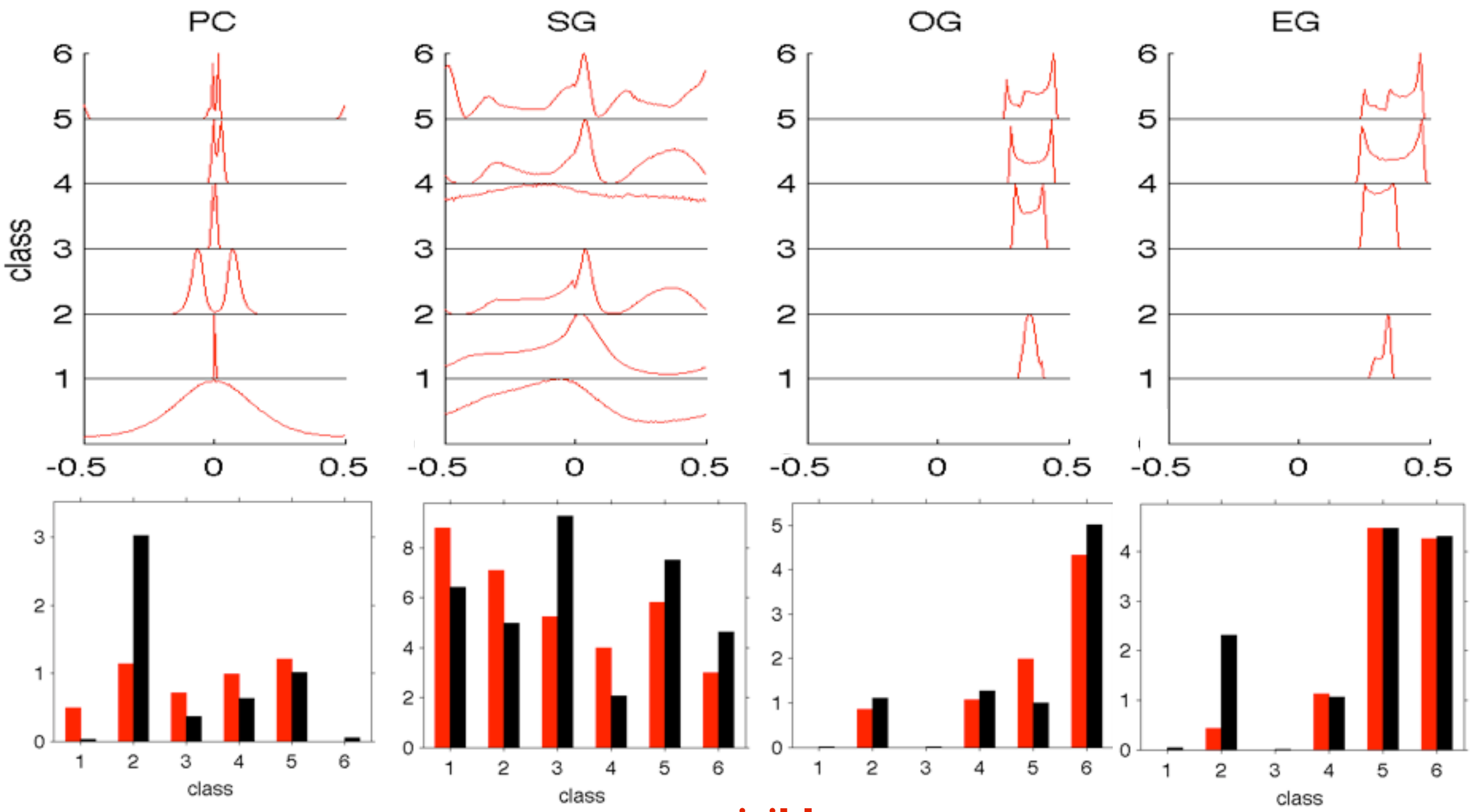


new Fermi J2238+58

Abdo et al. 2009, Science July 2

lightcurve morphologies with α and ζ

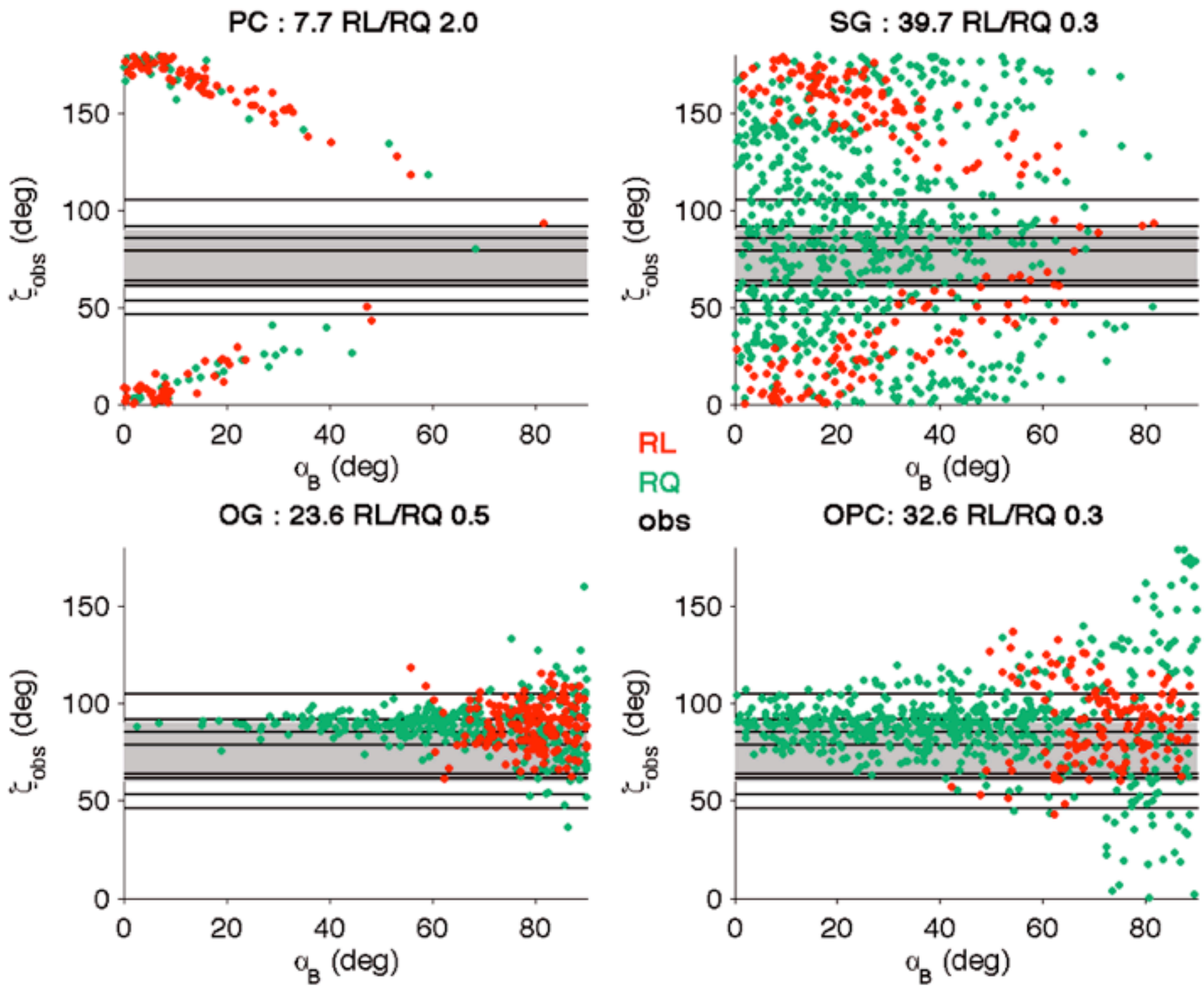
- little loss of morphological information in the visible sample



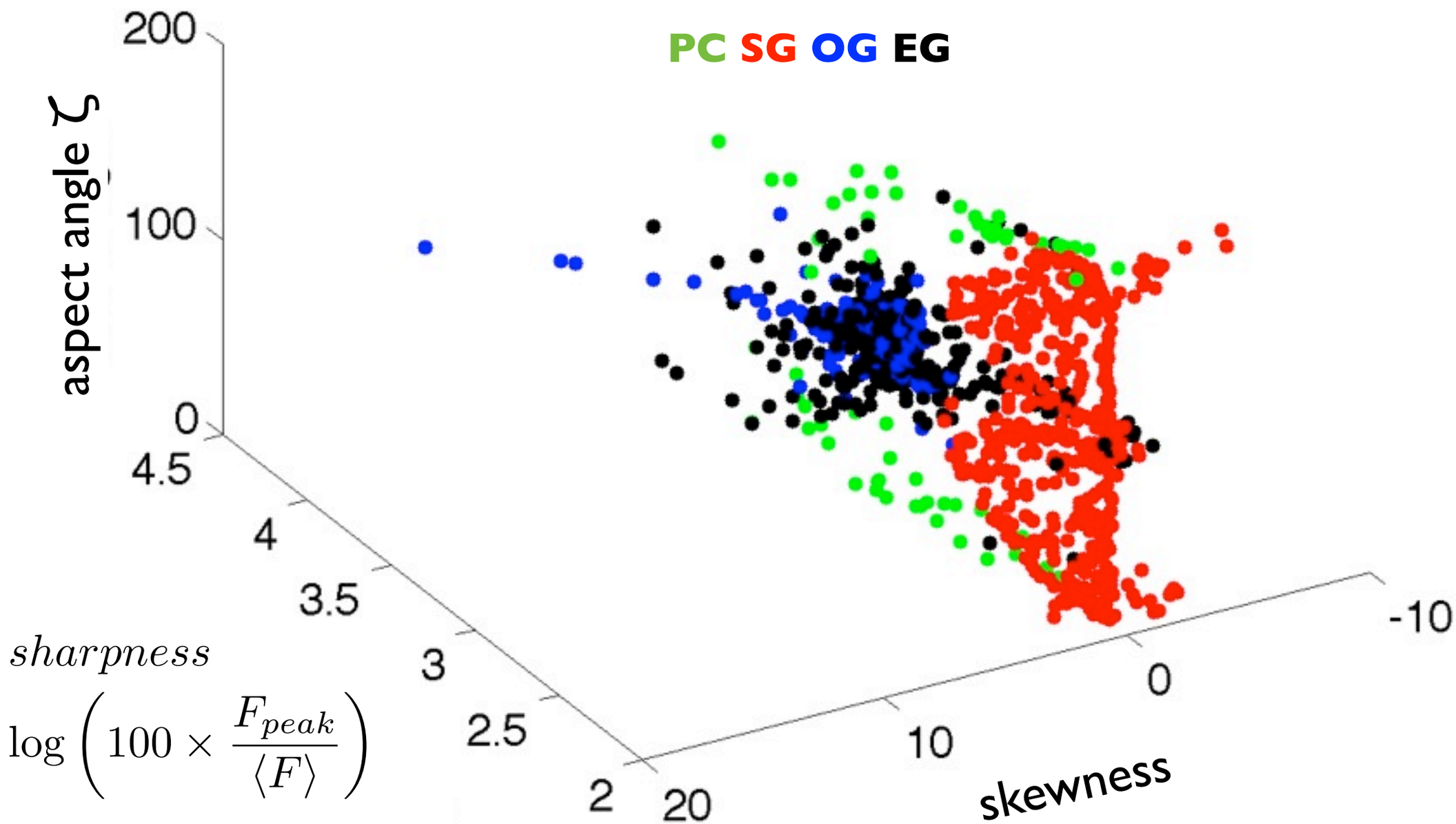
Pierbattista et al. arXiv: 1002.0324

orientations

- ζ constraints from PWN shape (Ng & Romani '04 '08) + Geminga tails (Caraveo et al. '03)



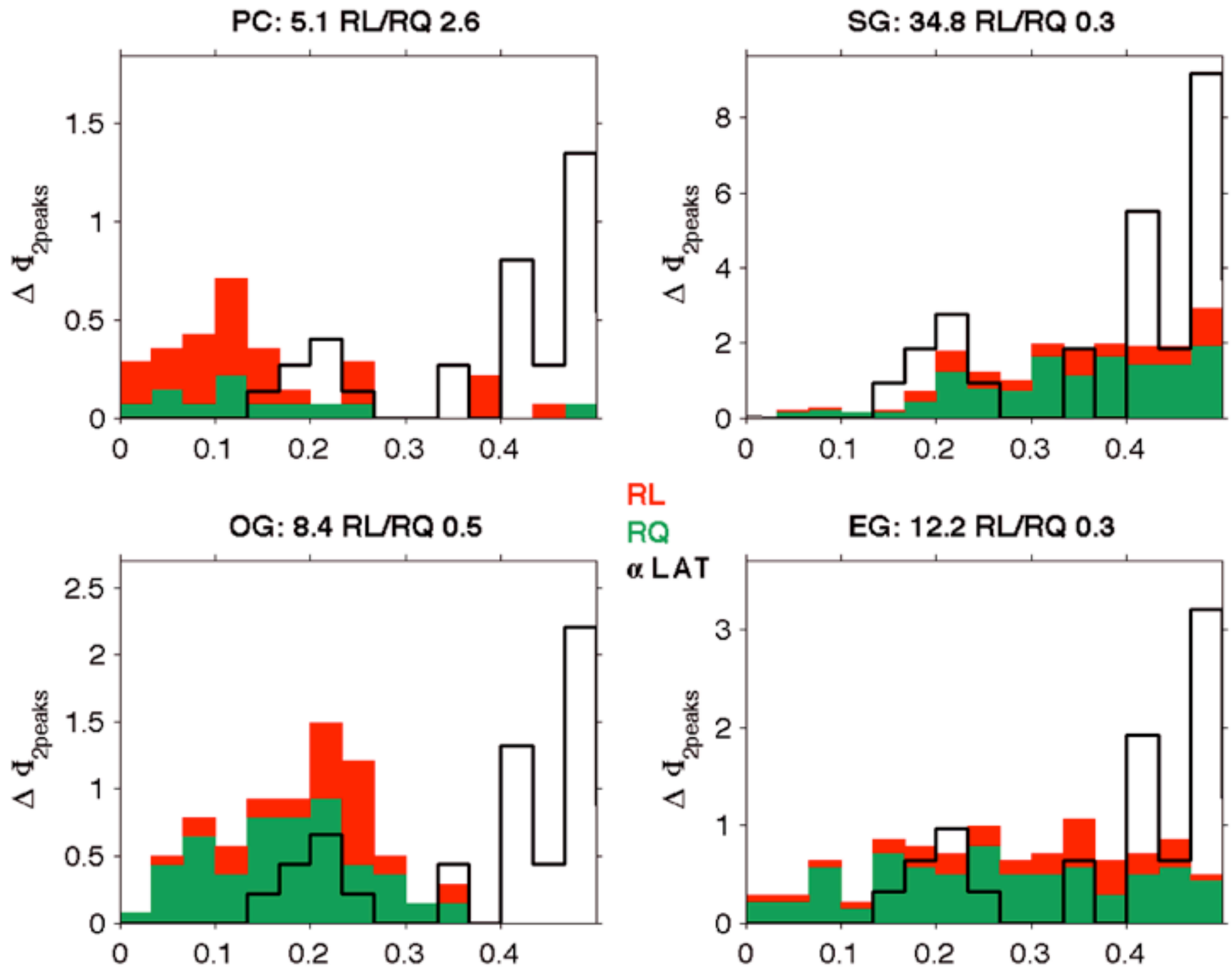
lightcurve shapes



Pierbattista et al. arXiv: 1002.0324

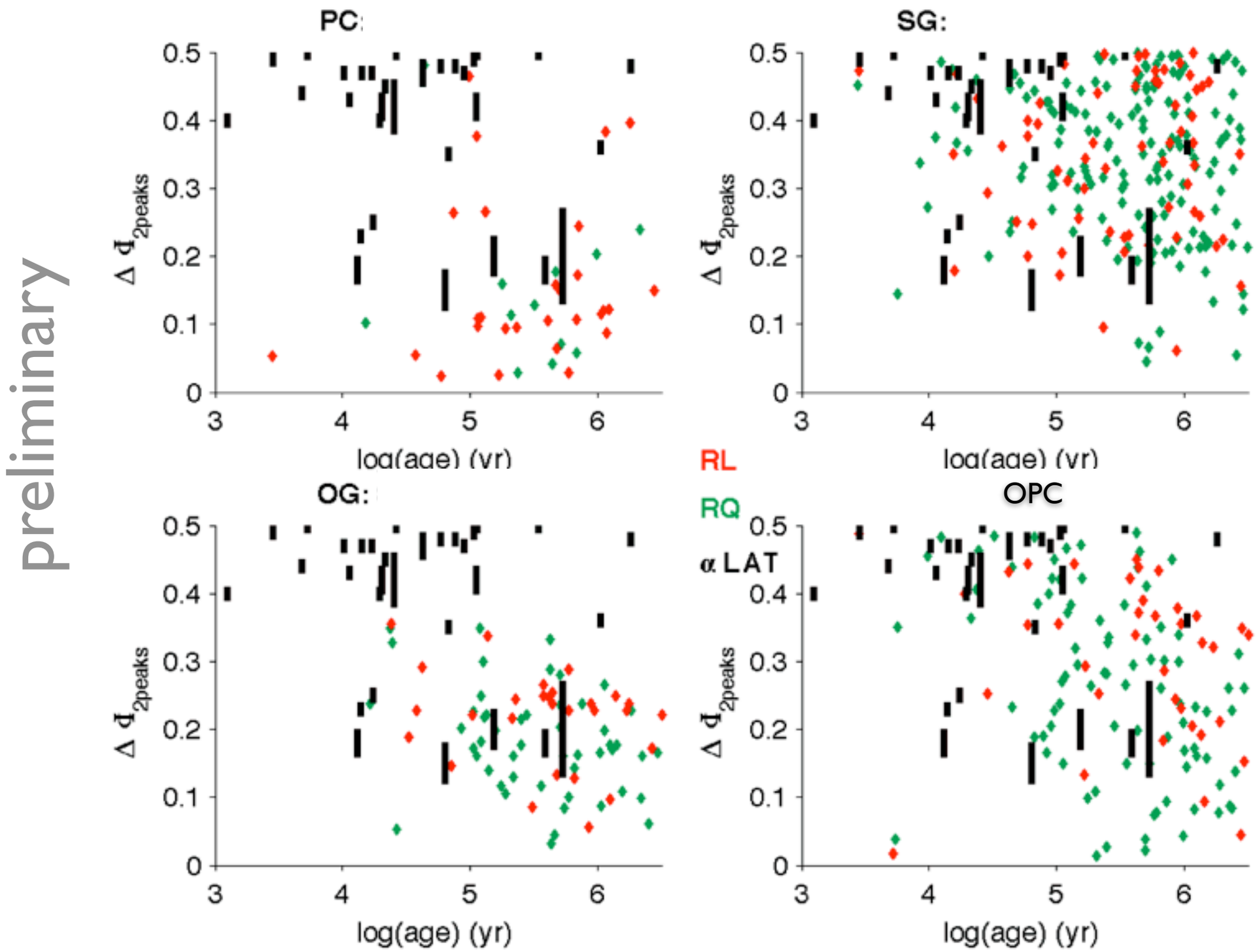
2-peak separation

- all models lack widely spaced peaks (e.g. from young, thin gaps)



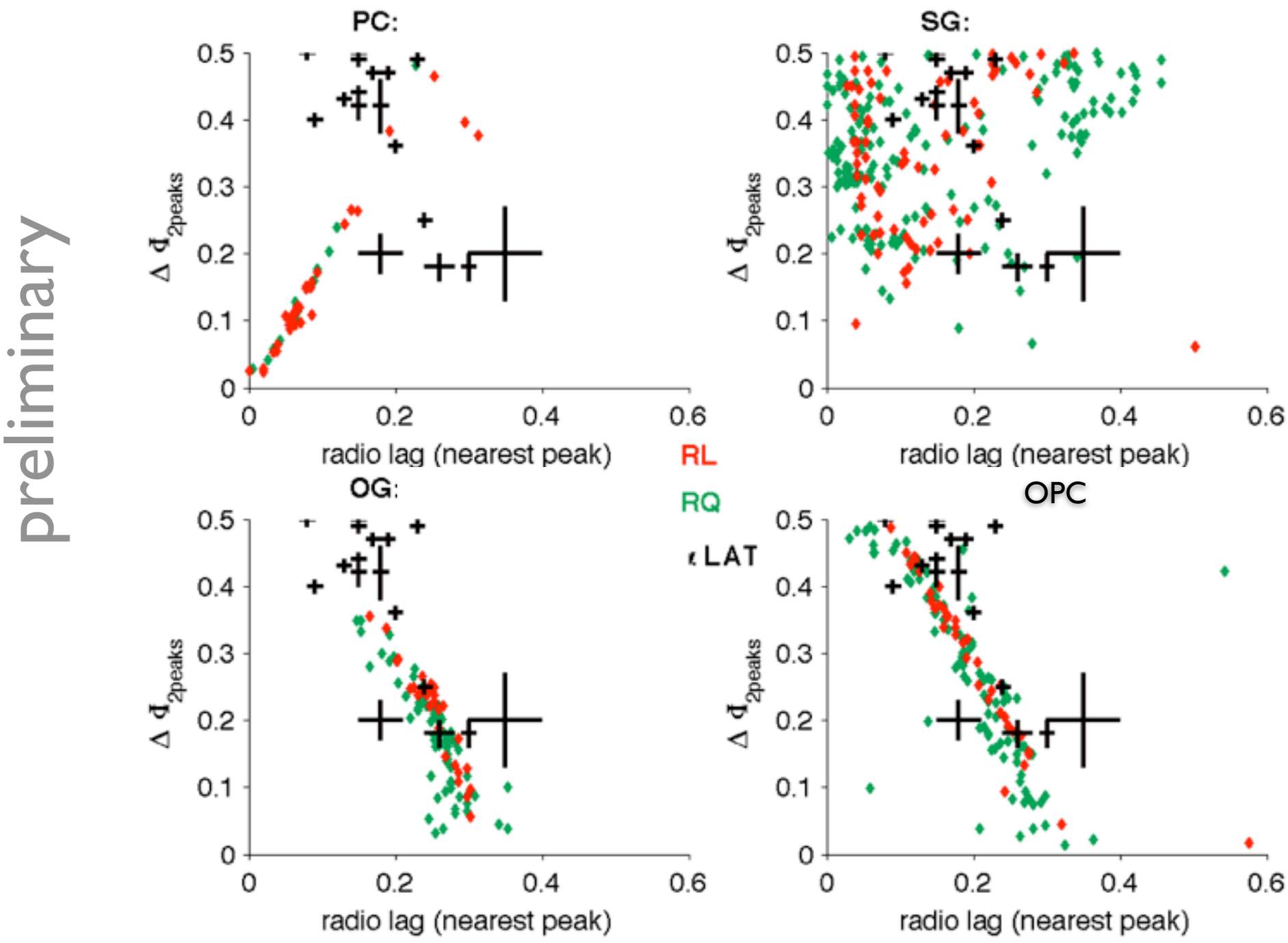
evolution of the peak separation

- none for the SG, more for the other models (pb for OG+EG)



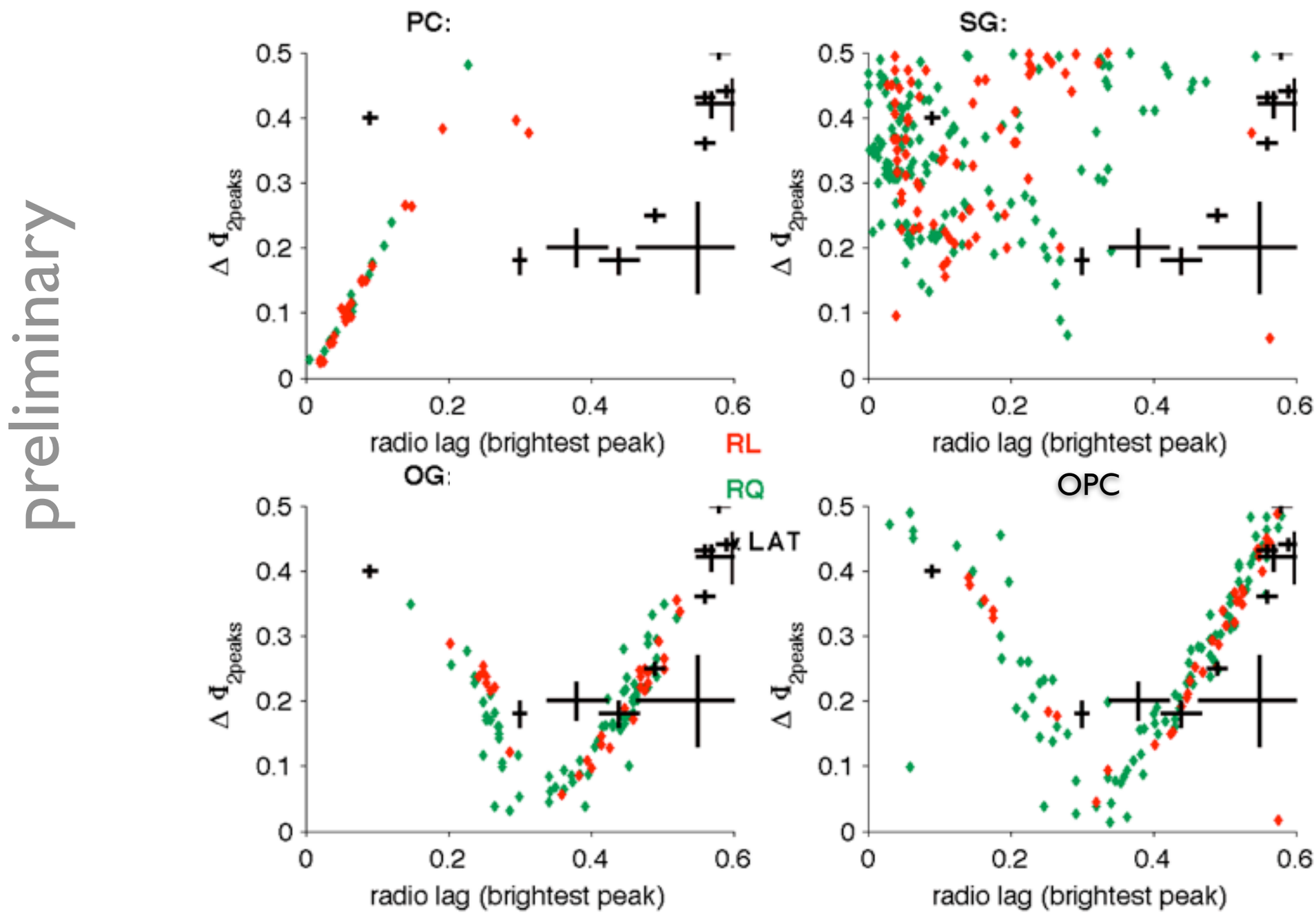
radio-γ lag

- nearest peak to the pole (sim) and to $\Phi_{radio} = 0$ (obs) (to be improved soon)
- obs. danger: S/N ratio, sim. danger: shoulder vs. 2nd peak



radio-γ lag

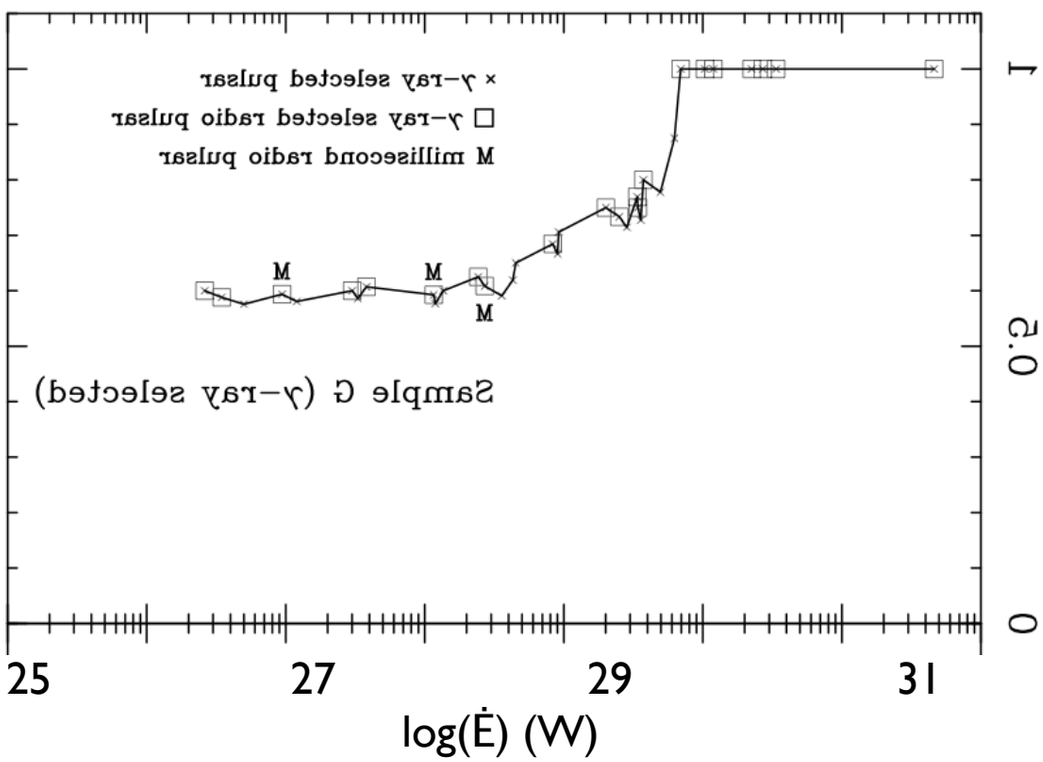
- brightest peak
- danger: energy dependent

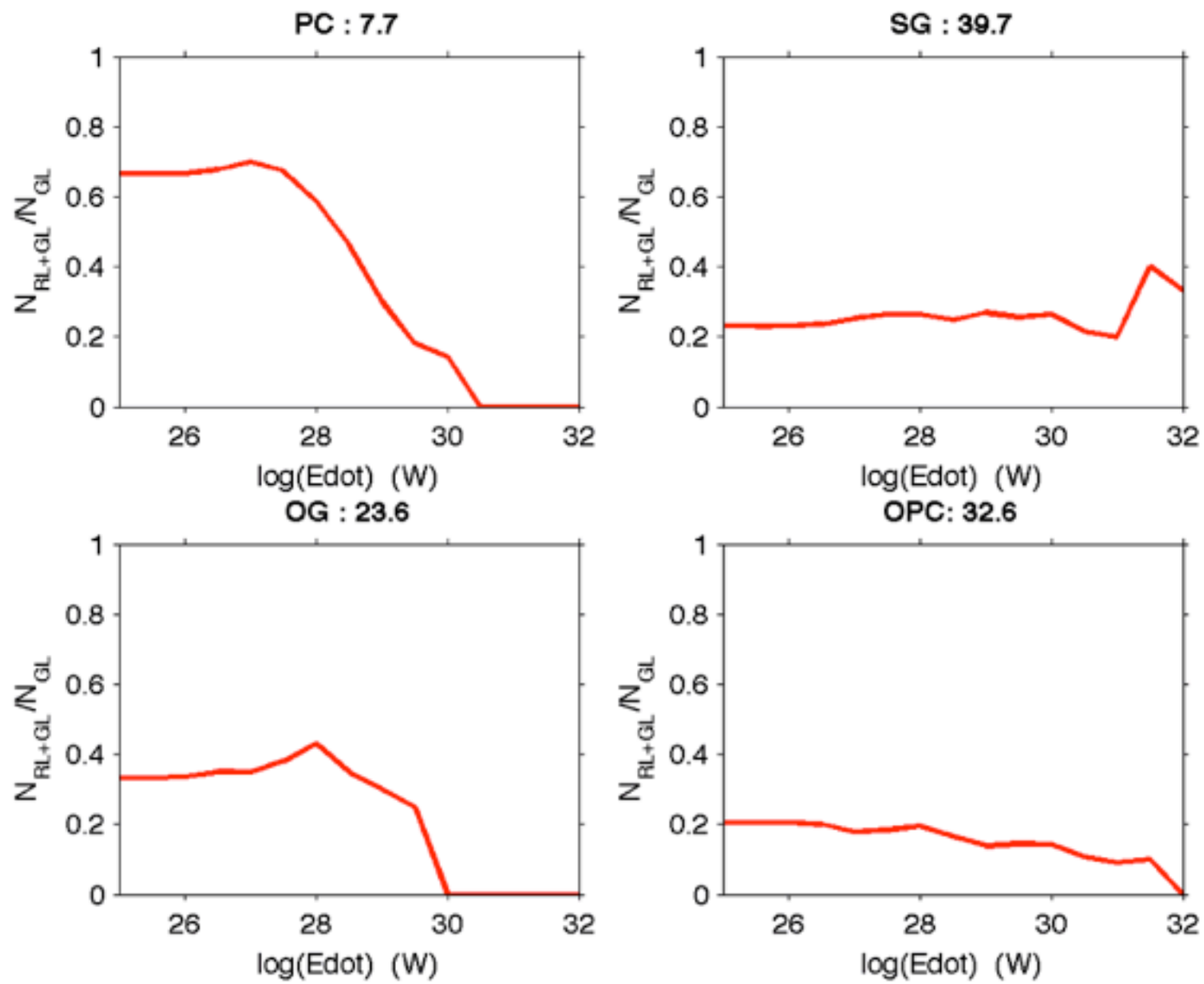


radio & γ beam apertures

- radio-loud fraction in γ-loud sample

Ravi et al. '10





radio & γ beam apertures

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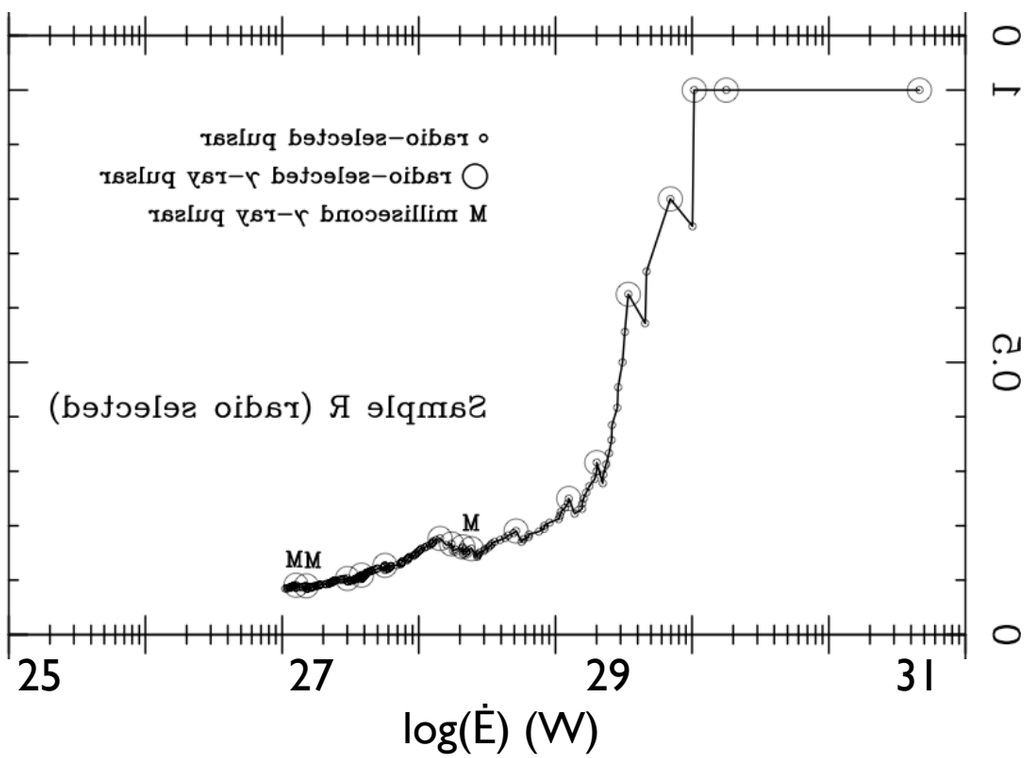
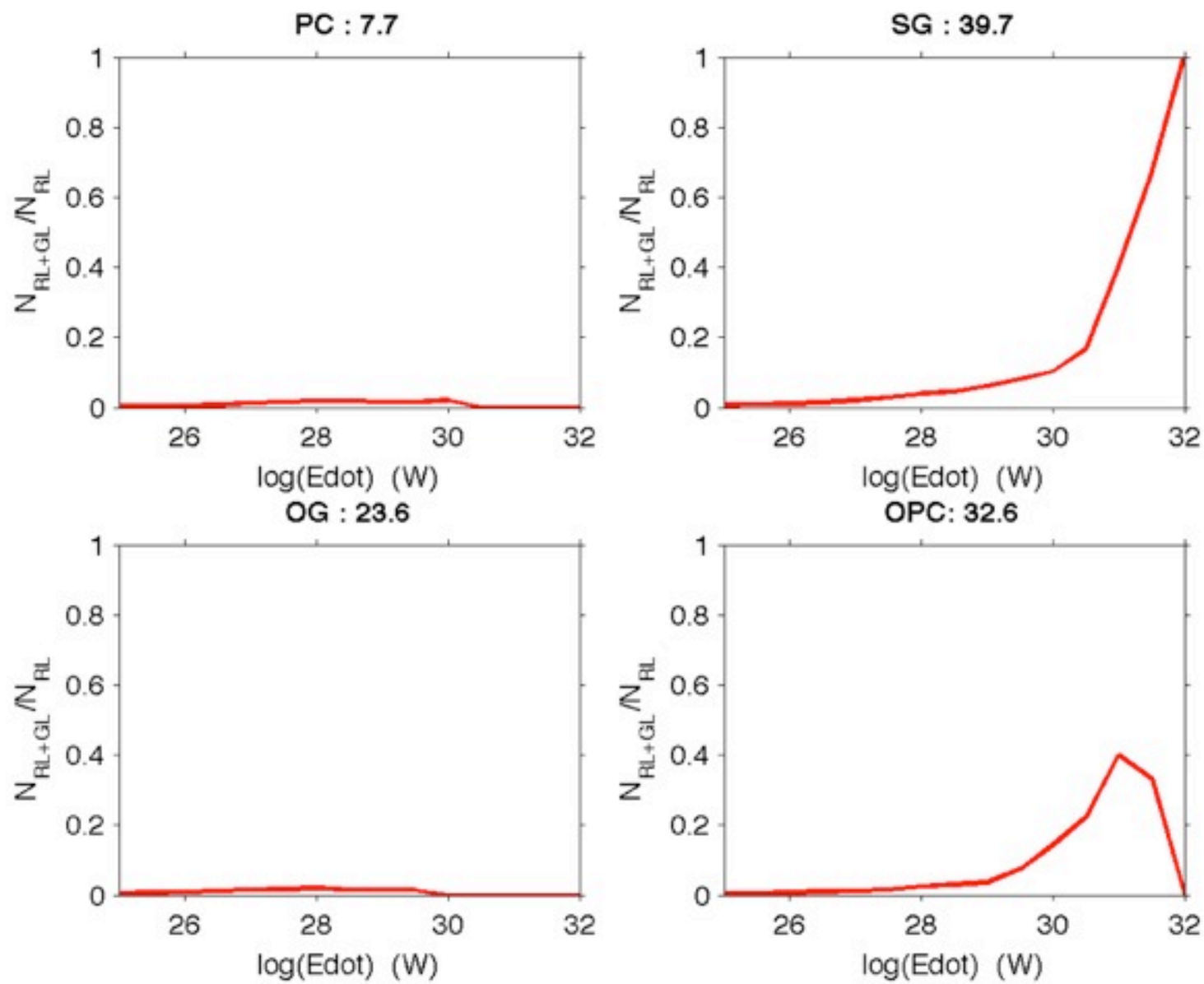
Ravi et al. '10

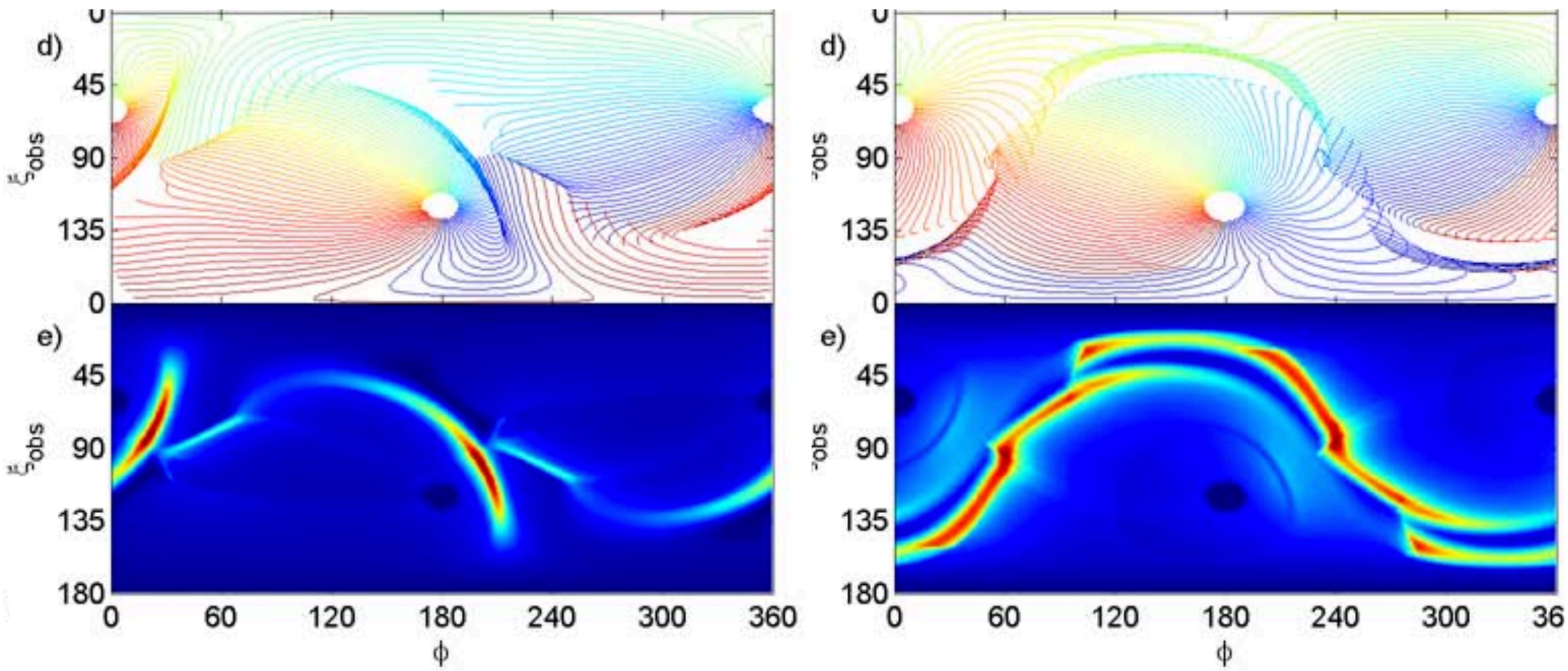




vacuum vs. force-free field

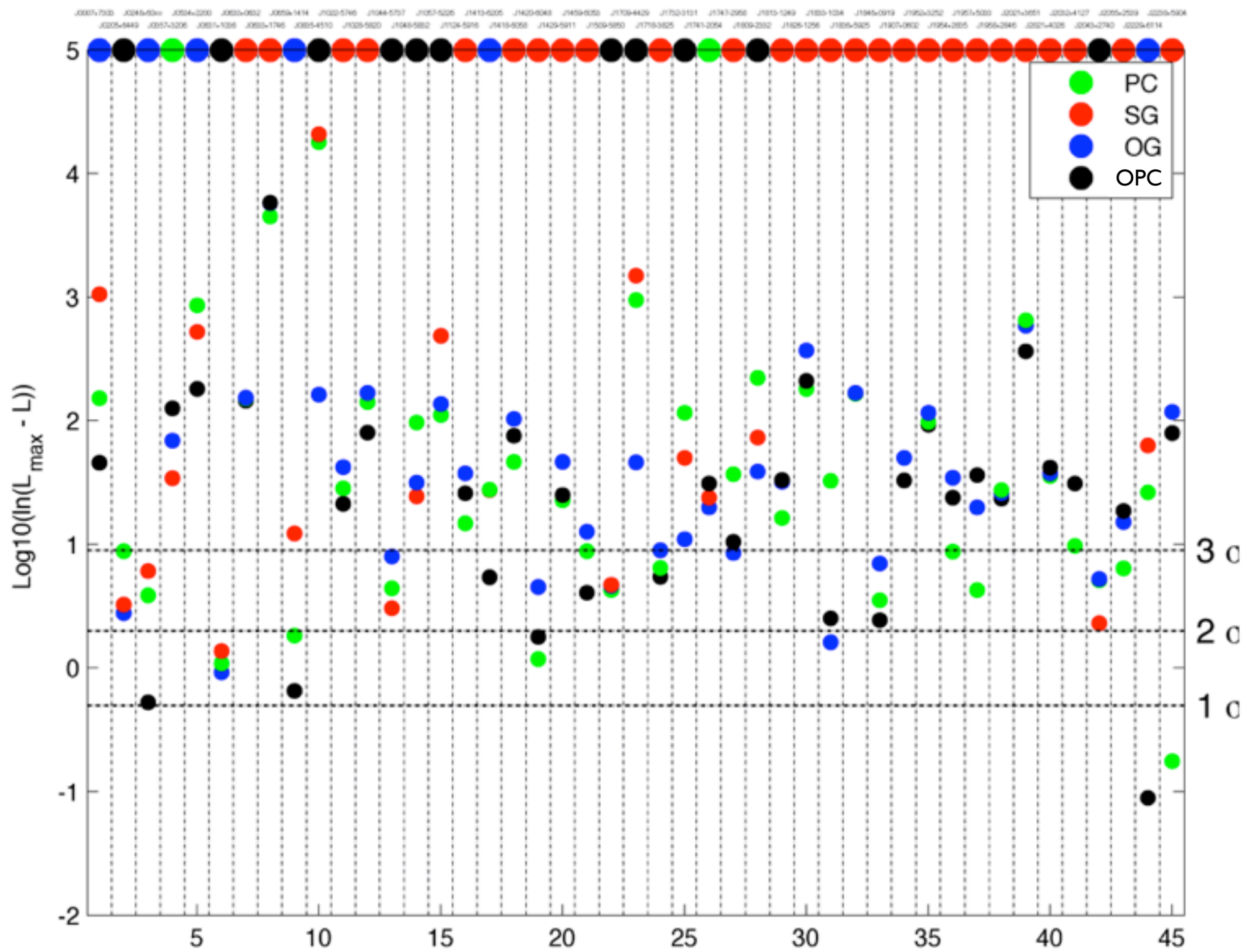
- vacuum field, emission at 0.9 θ_{PC}
- force-free field emission at 0.9 θ_{PC}

$\alpha = 60°$



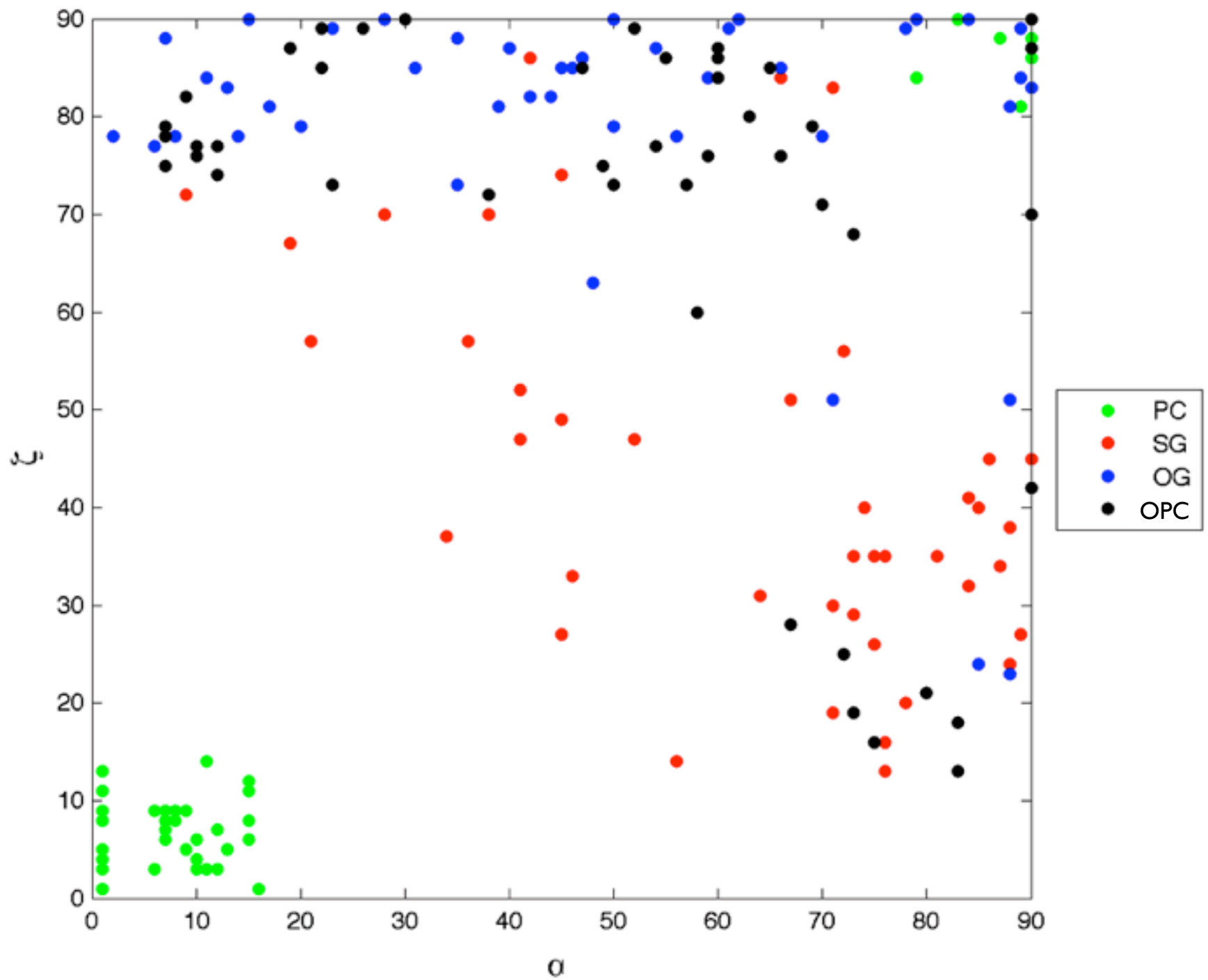
credit: Anatoly Spitkovsky

fitting the real Fermi pulsars profiles



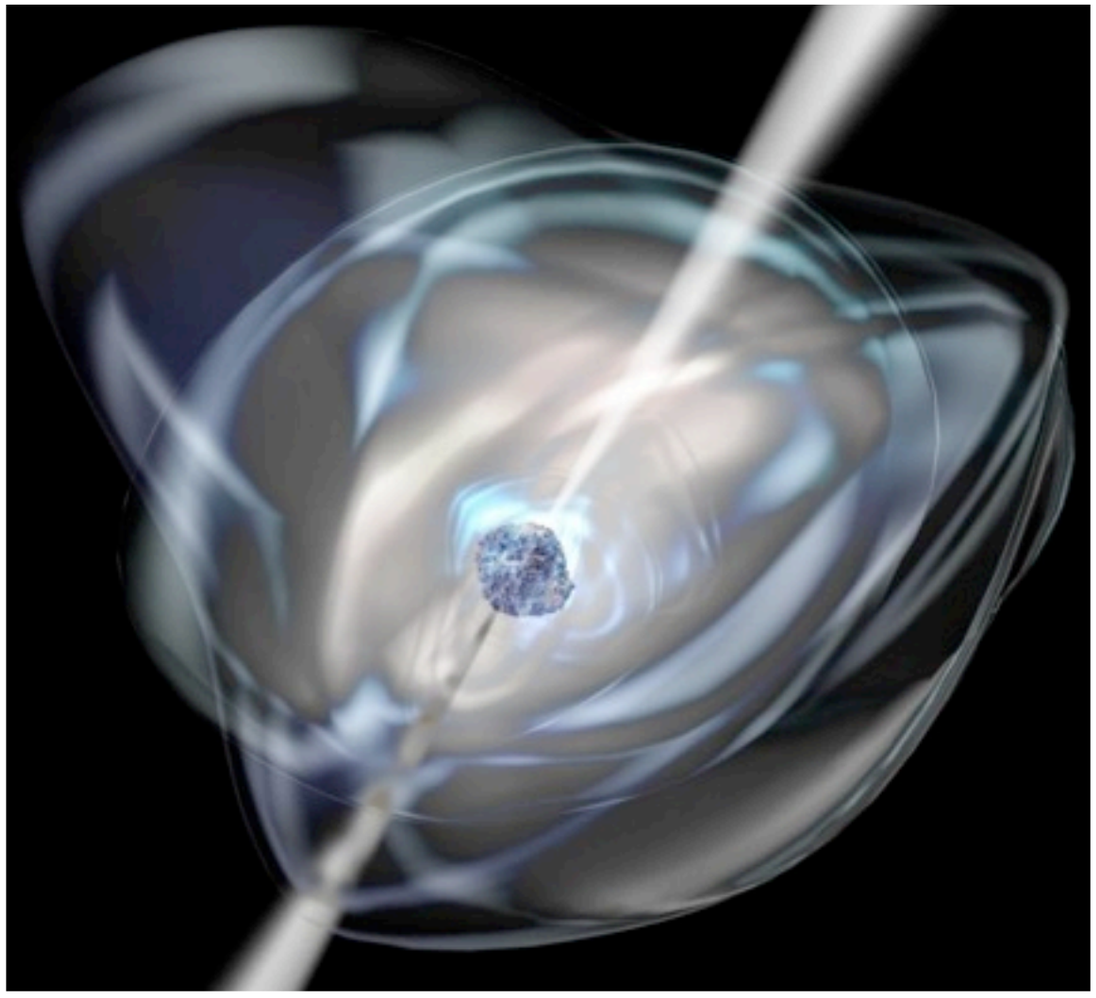
Fermi pulsar orientations

- joint γ-radio lightcurve fit underway to further constrain the orientations

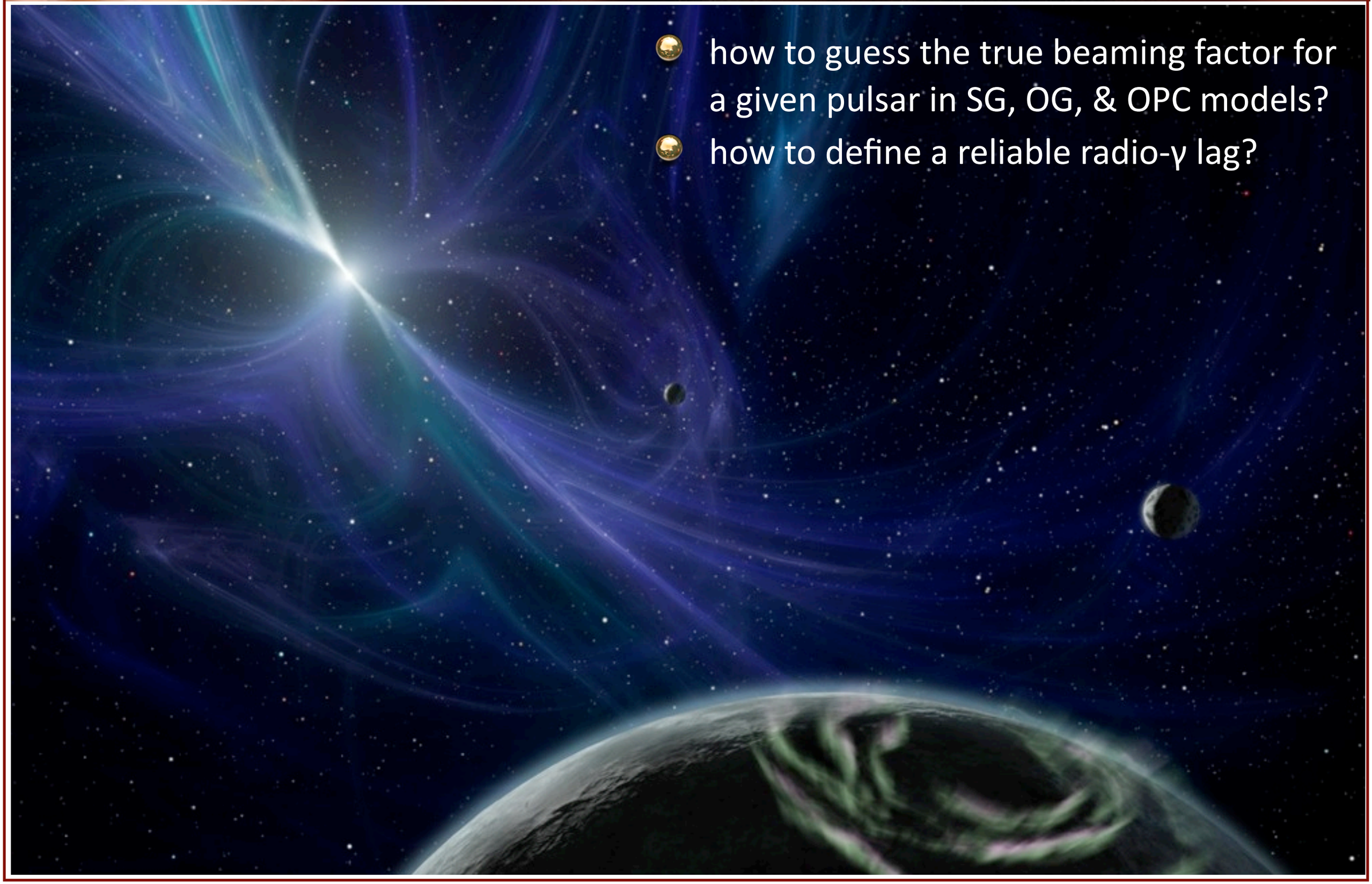


current conclusions

- no decisive clue favouring one gap over the others
  - degeneracy to fight with more observable parameters
  - γ-ray data probe pulsar evolution through P, $\dot{P}$ (need for more young pulsars)
  - radio-γ lag & large ζ from PWN may favour OPC over SG (what about force-free field?)
  - energetics, beam width & evolution may favour SG (with super GJ current) over OG and OPC
- big problem: ltc require thin gaps, luminosities require fat gaps
- still far from the truth...



short-term questions



- how to guess the true beaming factor for a given pulsar in SG, OG, & OPC models?
- how to define a reliable radio-γ lag?

long-term questions

- how well do we know the time evolution of 1-100 kyr-old pulsars?
  - is it constrained by the radio data skewed to old ages?
  - (B decay?, alignment with age?...)
- why do all models predict too few pulsars & not enough γL+RL at high Edot?
  - how to increase the GeV luminosity & pair multiplicity?
  - are the pulsars born at large obliquites?
- why don't we see PC emission?
- how to model the population of ms pulsars and their γ-ray luminosity evolution to assess their contribution to the Fermi sources?