Pair production and γ-ray emission in pulsars: A modern view

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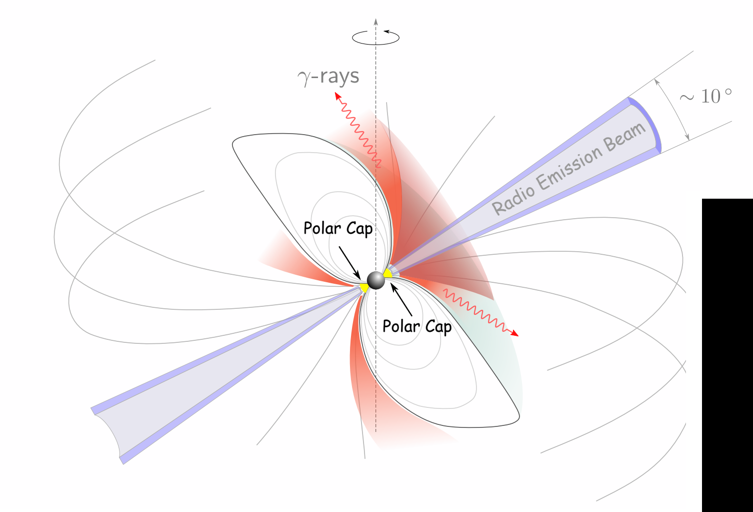
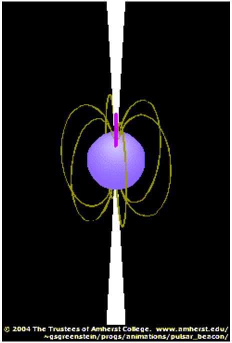
Pulsar: rapidly rotating magnetized neutron star

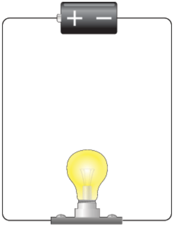
"Electric lighthouse"

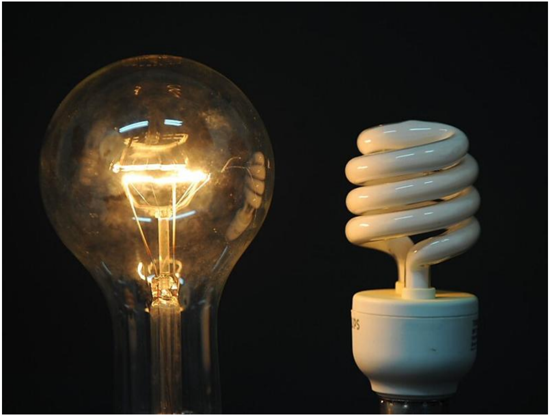




Pulsar: Cosmic Electrical Lighthouse

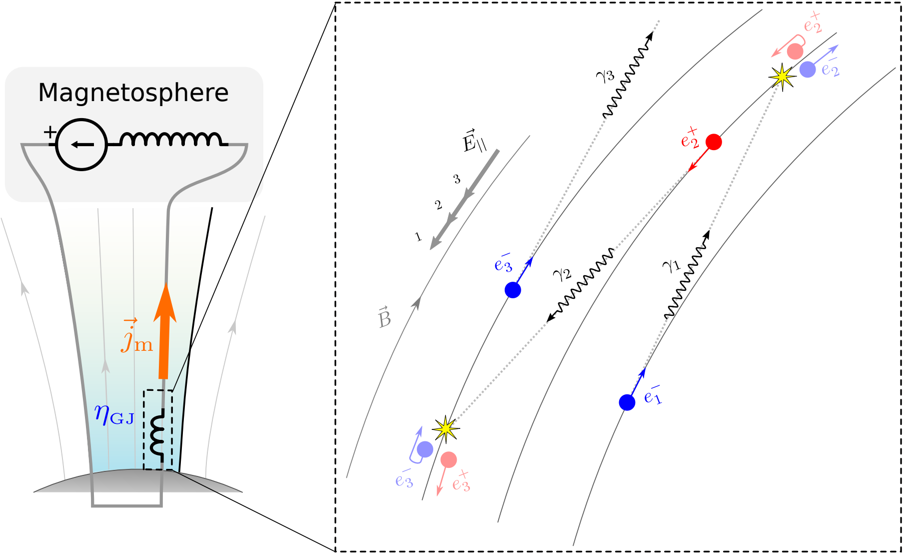
NB: Pulsars are non-thermal emitters





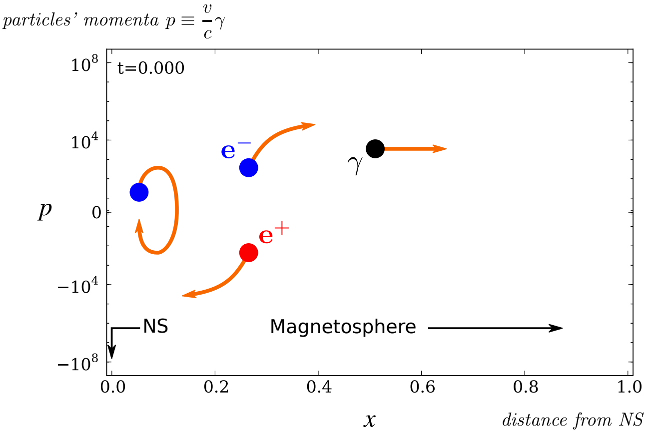
Plasma creation in the polar cap

Cascades are electromagnetically driven



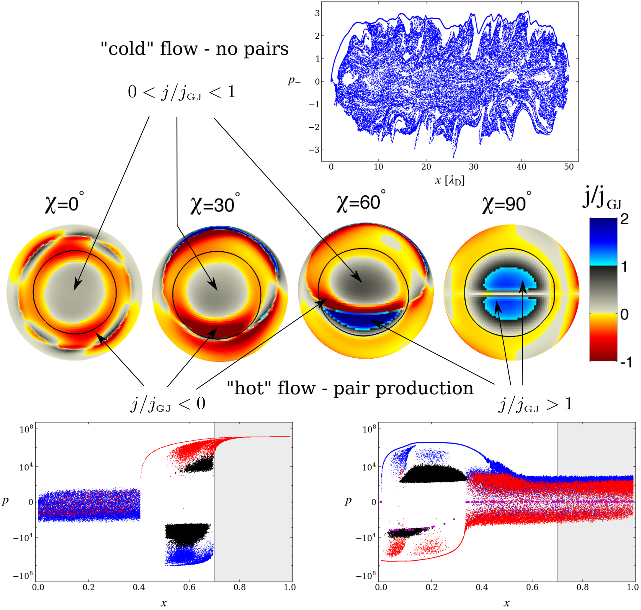
Limit cycle: series of discharges

No particles extraction from the NS



• electrons • positrons • γ-rays

Free particle extraction from the NS



Particles' momenta:
p~[0,10]

electrons

Polar cap currents

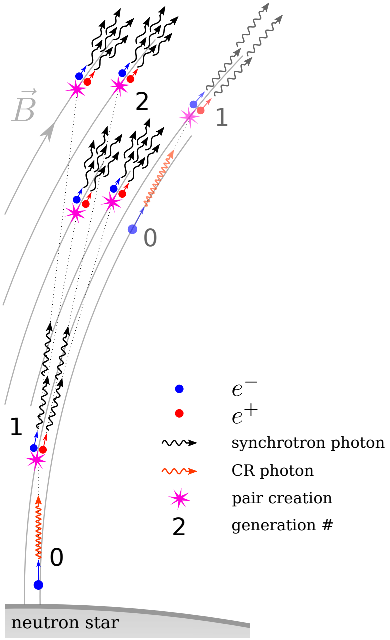
Particles' momenta:
p~[0,10^7]

electrons
positrons
photons

Full cascade

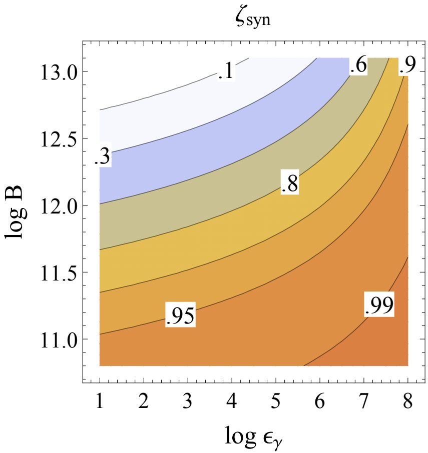
Synctrotron cascade

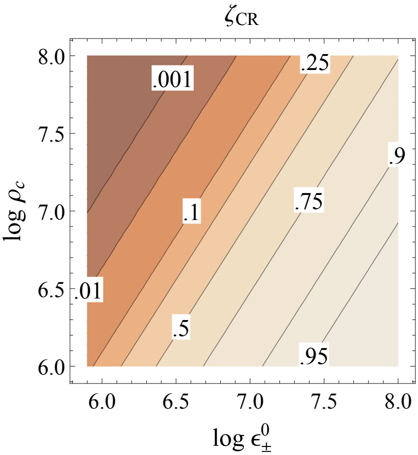
Curvature Radiation



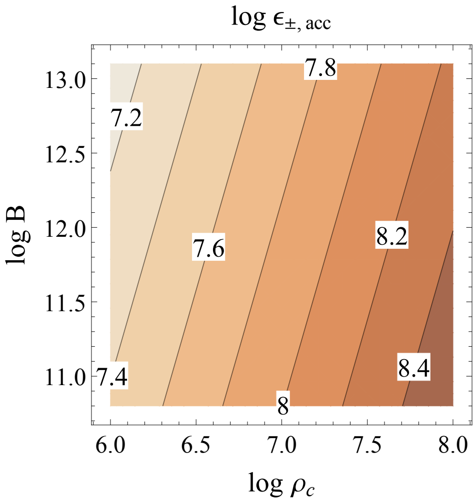
Cascade Efficiency

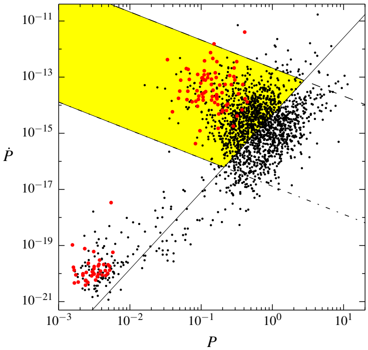
Fraction of particle energy going into synchrotron and curvature radiation





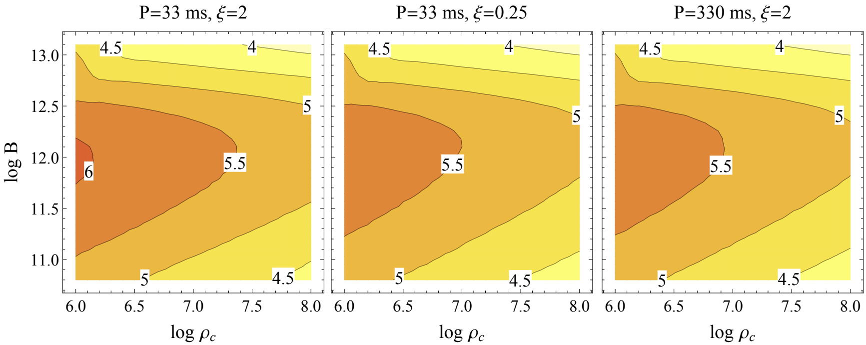
Particle acceleration





$$\epsilon_{\pm,\,\mathrm{acc}} \simeq 5 \times 10^7\, \chi_a^{2/7}\, \xi_j^{1/7} \rho_{c,7}^{4/7} P^{-1/7} B_{12}^{-1/7}$$

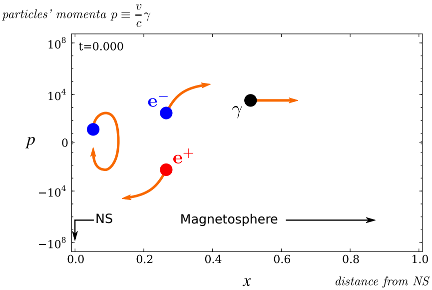
Multiplicity of polar cap cascade: $\kappa \sim 10^5$

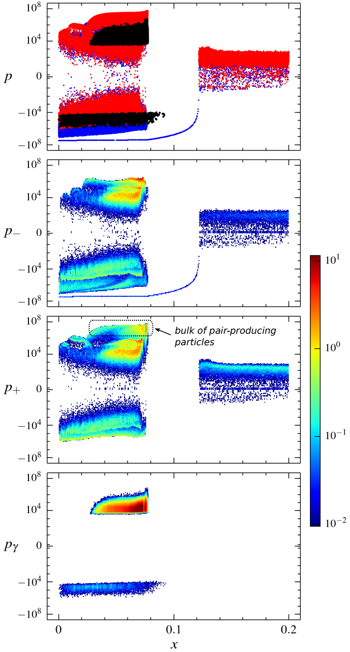


Dependence on ρ_c partially cancels out:

- small ρ_c $\longrightarrow$ high splitting efficienly, but low primary particle energy
- large ρ_c $\longrightarrow$ low splitting efficienly, but high primary particle energy

Discharge: RS flow

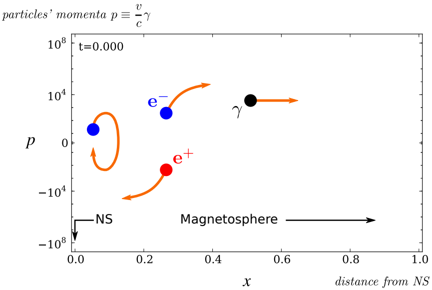


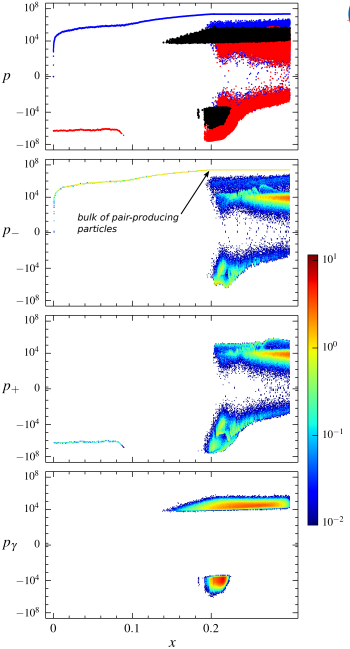


• electrons • positrons • γ-rays

- Low heating of NS surface
- Duty cycle: can be as low as $h_{\rm gap}/R_{\rm NS} \sim 1/100$ (for Crab)

Discharge: super-GJ SCLF

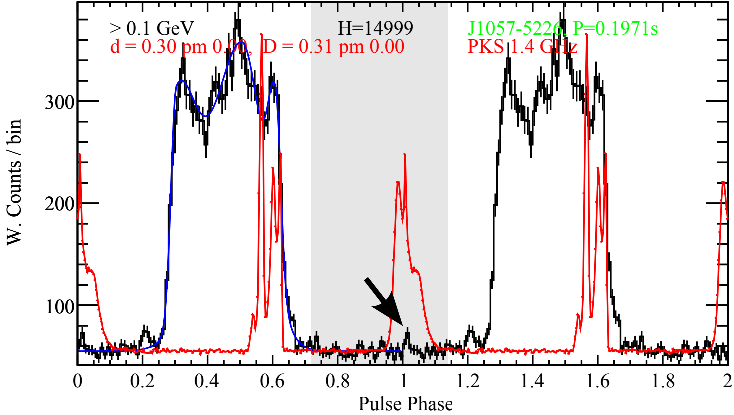




• electrons • positrons • γ-rays

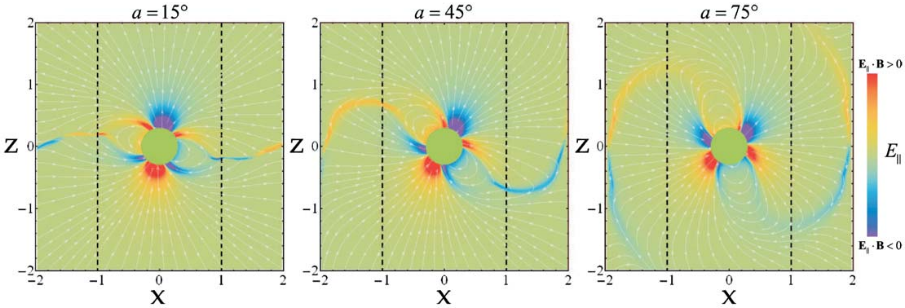
- Low heating of NS surface
- Duty cycle: $\sim 1/\text{few}$

PSR J1057-5226: Polar cap emission?



Electric field in resistive magnetosphere

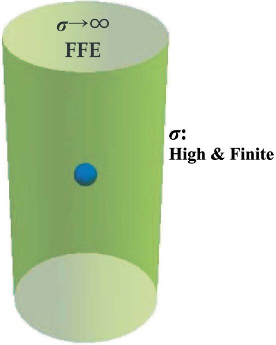
uniform high σ



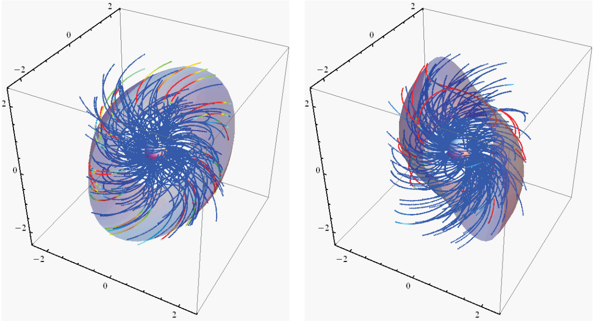
(Kalapotharakos et al. 2014)

Curvature radiation in magnetosphere with non-unifrom σ

$$\mathbf{v} = \left(\frac{\mathbf{E} \times \mathbf{B}}{B^2 + E_0^2} + f \frac{\mathbf{B}}{B} \right) c \qquad \frac{d\gamma_L}{dt} = f \frac{q_e c E_{\parallel}}{m_e c^2} - \frac{2 q_e^2 \gamma_L^4}{3 R_{\mathrm{CR}}^2 m_e c}$$

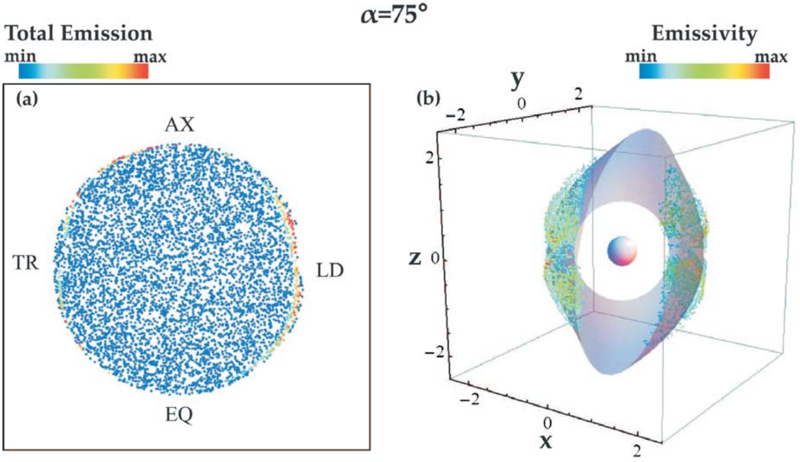


$\alpha = 45°$ $\qquad$ $\alpha = 90°$



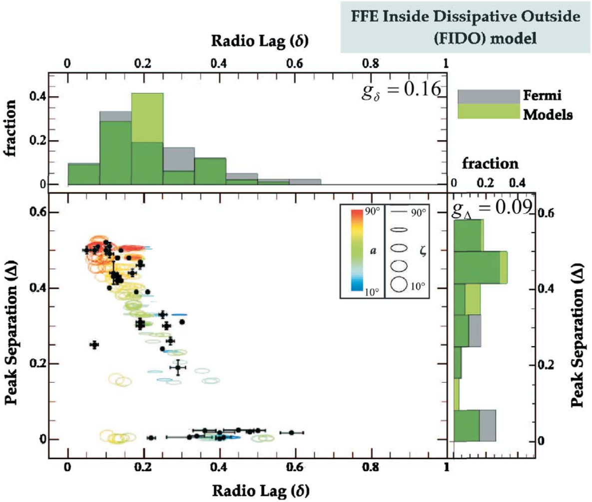
(Kalapotharakos et al. 2014)

γ-ray Emitting Regions



(Kalapotharakos et al. 2014)

Peak Separation(Δ) vs Radio Lag (δ)



(Kalapotharakos et al. 2014)

Conclusions

- Particles can be accelearted faster and at lower altitudes
- γ-ray emission from polar caps is at lower energies ($\sim 10 - 100$ MeV)
- Maximum multiplicity of polar cap cascades $\kappa \sim 10^5$
  - Maximum multiplicity is not sensitive to pulsar parameters
  - Plasma distribution is non-uniform
  - Inclinations angle should be very important factor determining the overall pulsar pair multiplicity
- The bulk of γ-ray emission seems to come from the current sheet region outside the light cylinder