Particle Acceleration and Pair Production in Pulsar Winds

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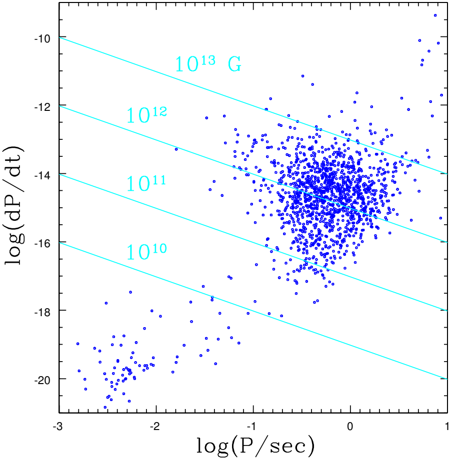
Kinetic modelling of astrophysical plasmas, Krakow, 5th - 9th October 2008

Outline

1. Pair production in pulsars
2. Pair production in laser light
3. Particle trajectories in an E-M wave
4. Counter-propagating laser beams
5. Pair production in pulsar winds

Surface field
$B \sim B_{\rm crit} = 4.4 \times 10^{13}\,\mathrm{G}$



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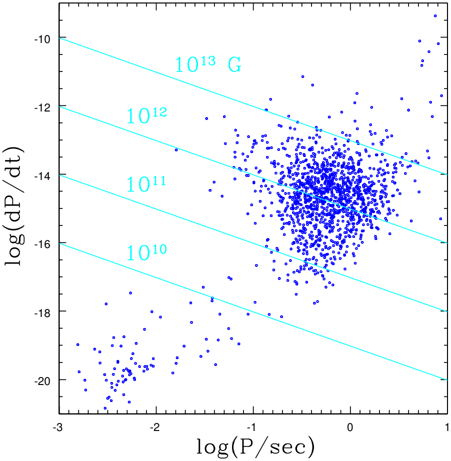

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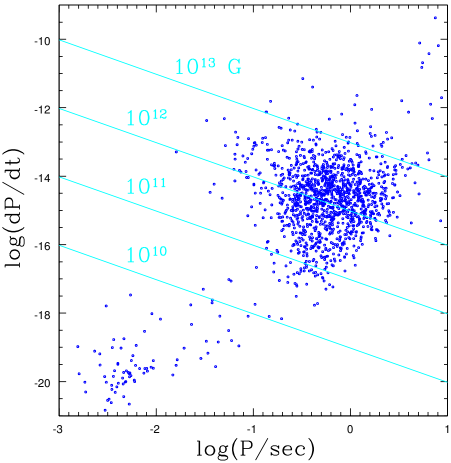

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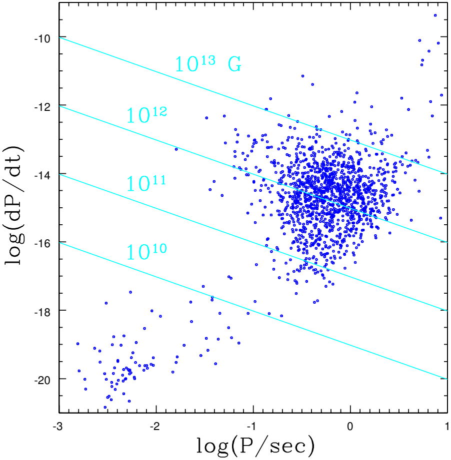

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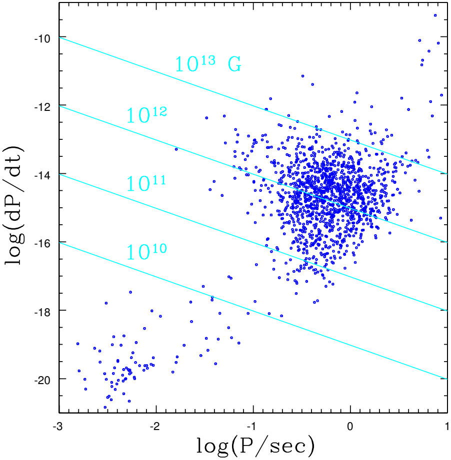
- Conflicts with PWN obs.(de Jager 2007)
- Time-dependent cascade models? (e.g., Timokhin, this workshop)



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- Pair production by electron requires

$$\eta \;=\; \gamma \frac{B'_\perp}{B_{\text{crit}}} \sim 1$$

or, equivalently $\gamma E'_\perp / E_{\text{Schwinger}} \sim 1$
(component of acceleration perp. to $\boldsymbol{v}$ important)

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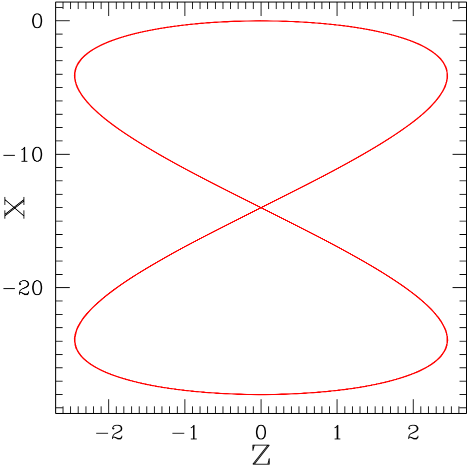
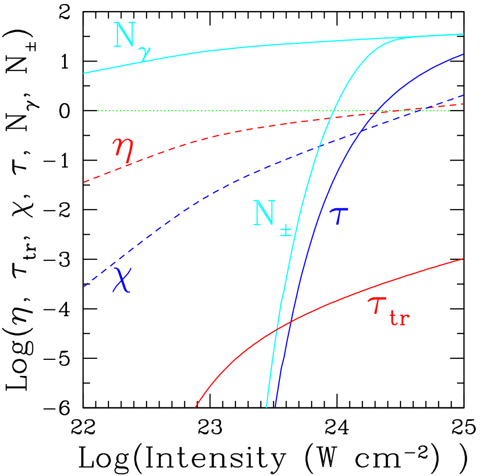
Laser: $a = 840\sqrt{I_{24}\lambda_{\mu\mathrm{m}}}$,
Pulsar: $a = 2.6 \times 10^7 \sqrt{\dot{P}_{15}/P^3}\, r_{\mathrm{L}}/r$

- E-M wave in $\hat{\boldsymbol{z}}$ direction
- $\boldsymbol{E}$ along $\hat{\boldsymbol{x}}$
- $\boldsymbol{E} = -\hat{\boldsymbol{z}} \times \boldsymbol{B}$ Lorentz force vanishes for $\boldsymbol{v} \to c\hat{\boldsymbol{z}}$
- No cancellation for periodic orbit, but $B' = B/a$, so threshold is

$$\begin{aligned} \eta &\approx \gamma B'/B_{\rm crit} \\ &= (\gamma/a)B/B_{\rm crit} \end{aligned}$$

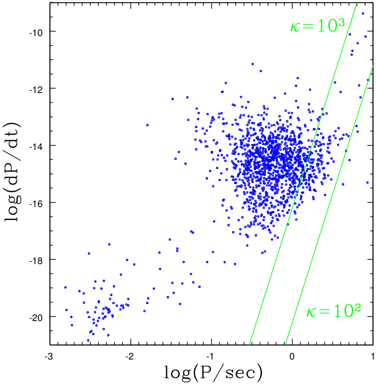


- Counter-propagating beams
- Pair production at node $\boldsymbol{B} = 0$
- Hot spot size $\approx \lambda_{\rm laser}$
- Production via virtual photon dominates at $\eta \lesssim 0.5$
- For $\eta > 0.8$, cascade via real (curvature) photon
- Radiation reaction important for $\eta > 0.5$

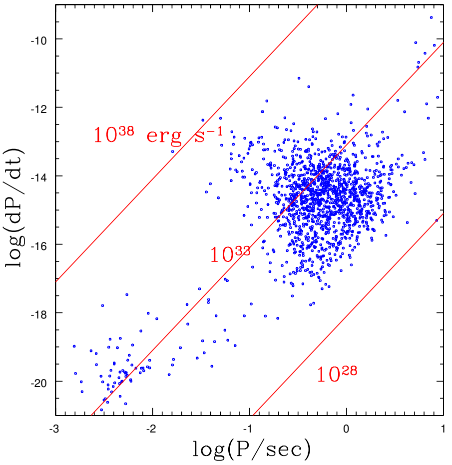


Bell & Kirk
arXiv:0808.2107

- Current starvation in striped wind $B \propto 1/r$, $n \propto 1/r^2$
- Complete dissipation of Poynting flux impossible if $\kappa < 2 \times 10^3 \dot{P}_{15}^{1/4} P^{-9/4}$
- E-M wave in outer wind
- "Reflection" at termination "shock"?



- Assume presence of a reflected wave
- Threshold $\propto \gamma B \propto 1/r^2$
- Very rapid rise in production rate inside $r_{\mathrm{threshold}}$
- Pair production possible if $r_{\mathrm{threshold}} > r_{\mathrm{L}}$.



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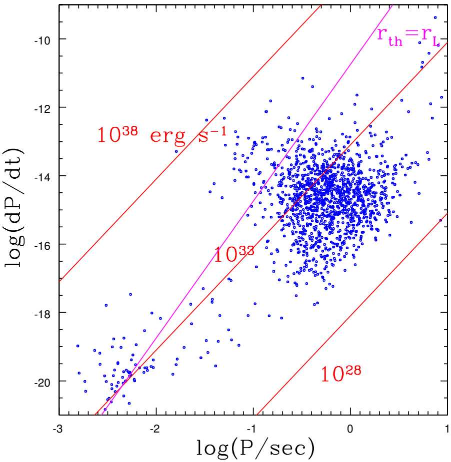

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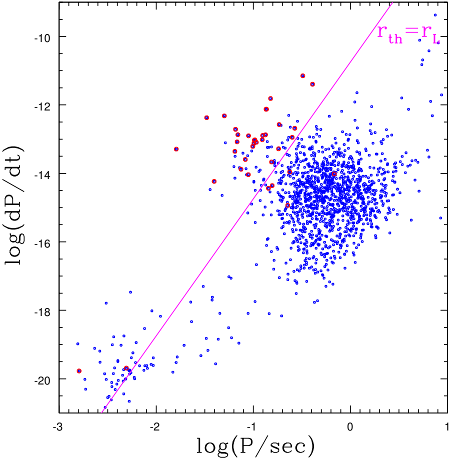

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- Colliding laser beams expected to produce pairs in lab.
- Pair production in pulsar wind/wave cavity may be possible