Particle Acceleration

in

relativistic flows

John Kirk

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Germany

Astrophysical flows *ideal* (Reynolds number $\gg 1$)

Acceleration sites

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Dissipation of kinetic energy by shocks, shear, boundary layers e.g.,

- pulsar wind termination shock
- jet recollimation/termination shocks
- jet/jet spine interface
- differentially rotating jet

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Dissipation of magnetic energy at current sheets e.g.,

- striped pulsar wind
- magnetic shear layer in jet

Dissipation of kinetic energy

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- Shear, boundary layer: idealised picture $f \propto p^{-3+\alpha}$ depending on scattering rate. Relatively slow, more effective for protons Stawarz & Ostrowski 2002; Rieger & Duffy 2004

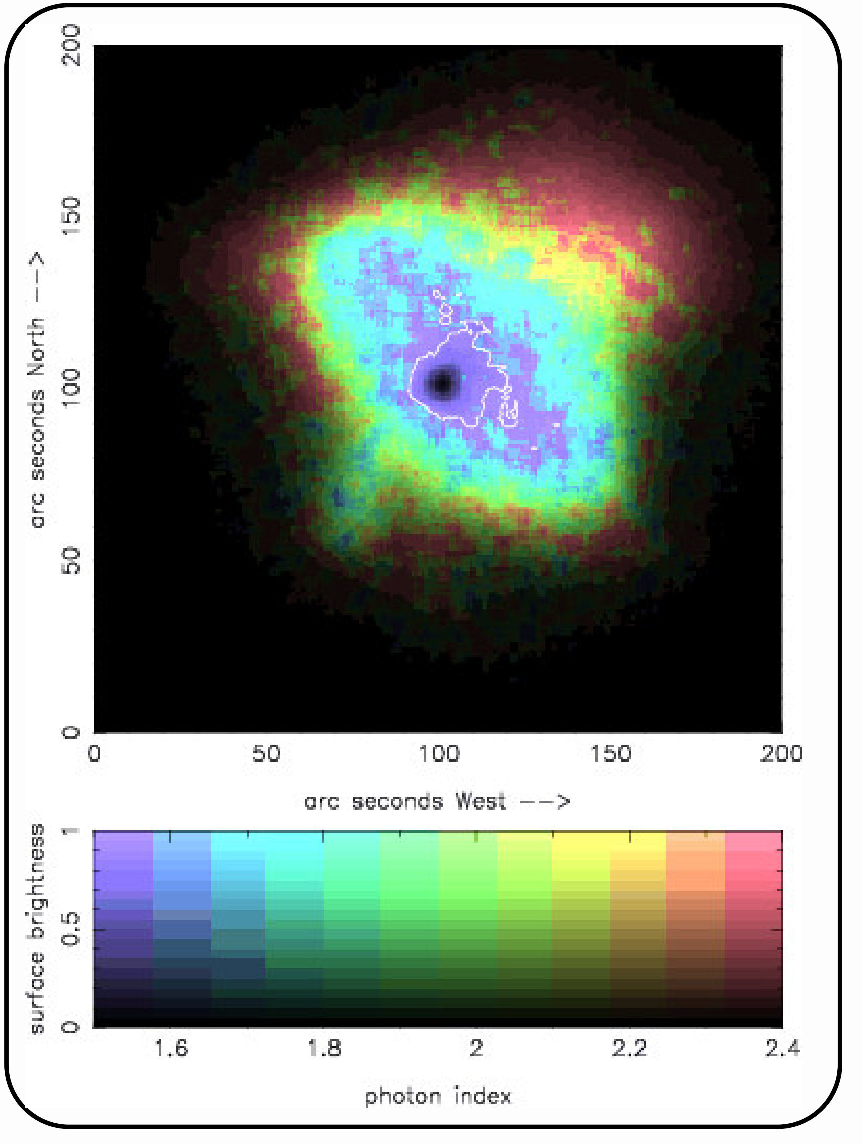
Crab Nebula

XMM-Newton
Willingale et al 2001

$$N(\gamma) \quad \propto \quad \gamma^{2-s}$$

Centre: $s \approx 4.2$

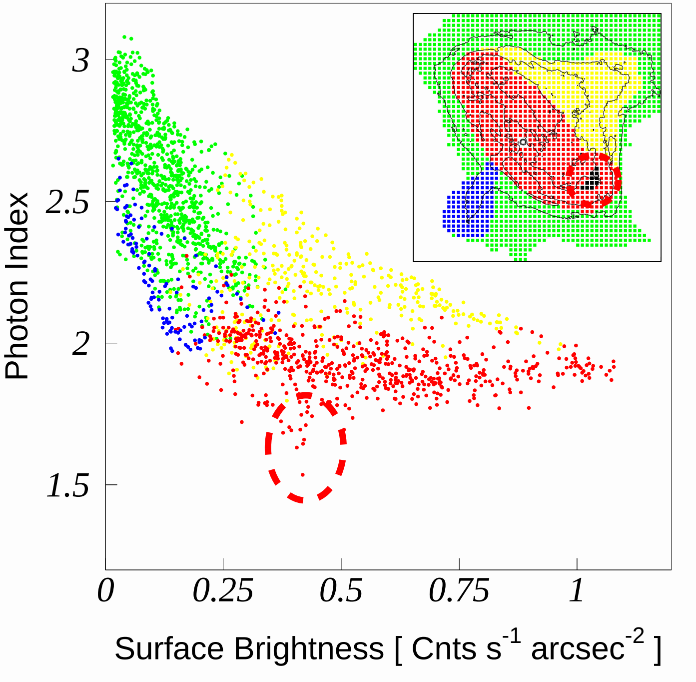
Edge: $s \approx 4.2 + 1$



Crab Nebula

Chandra

Mori et al 2004



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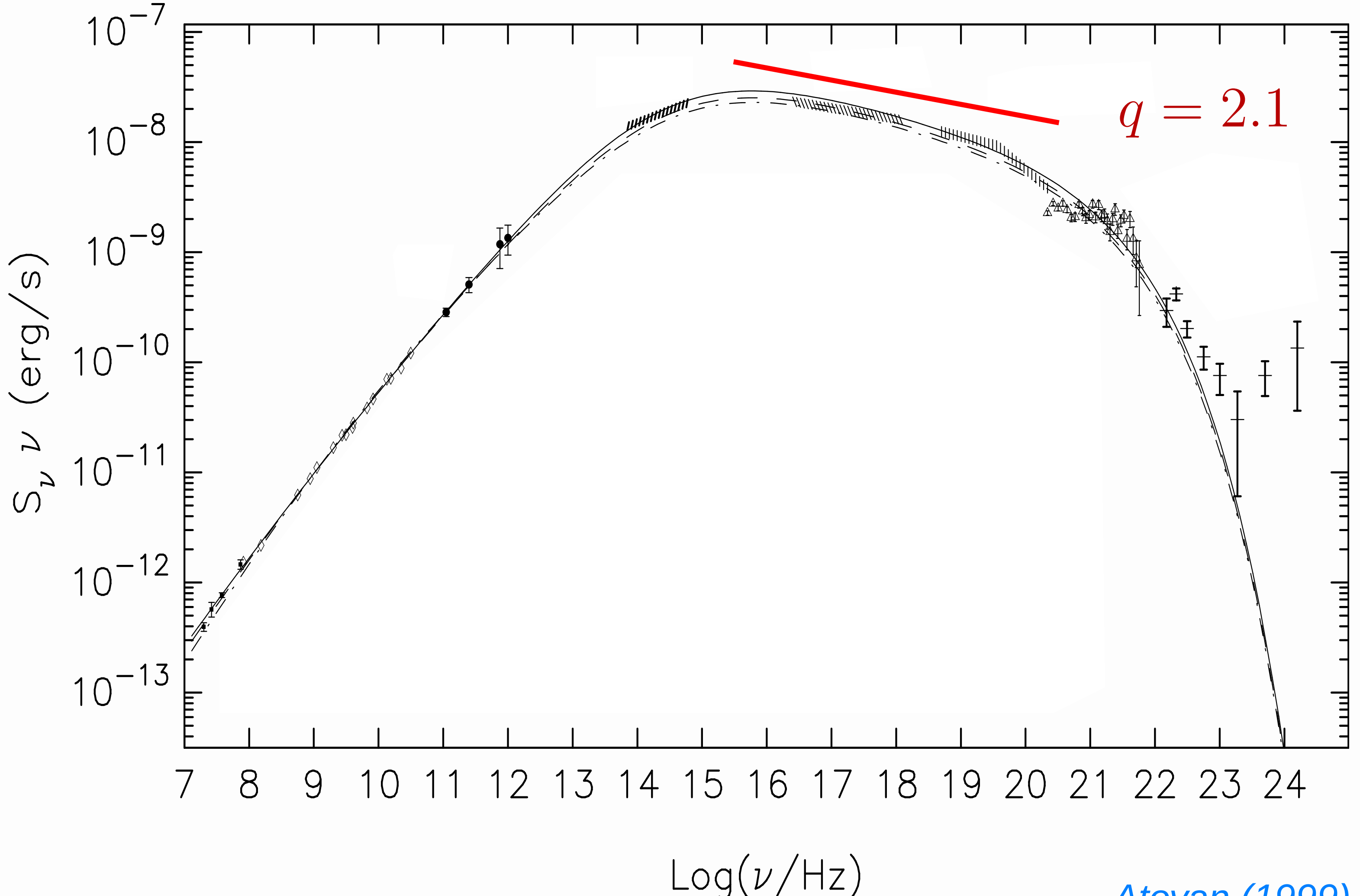

Atoyan (1999)

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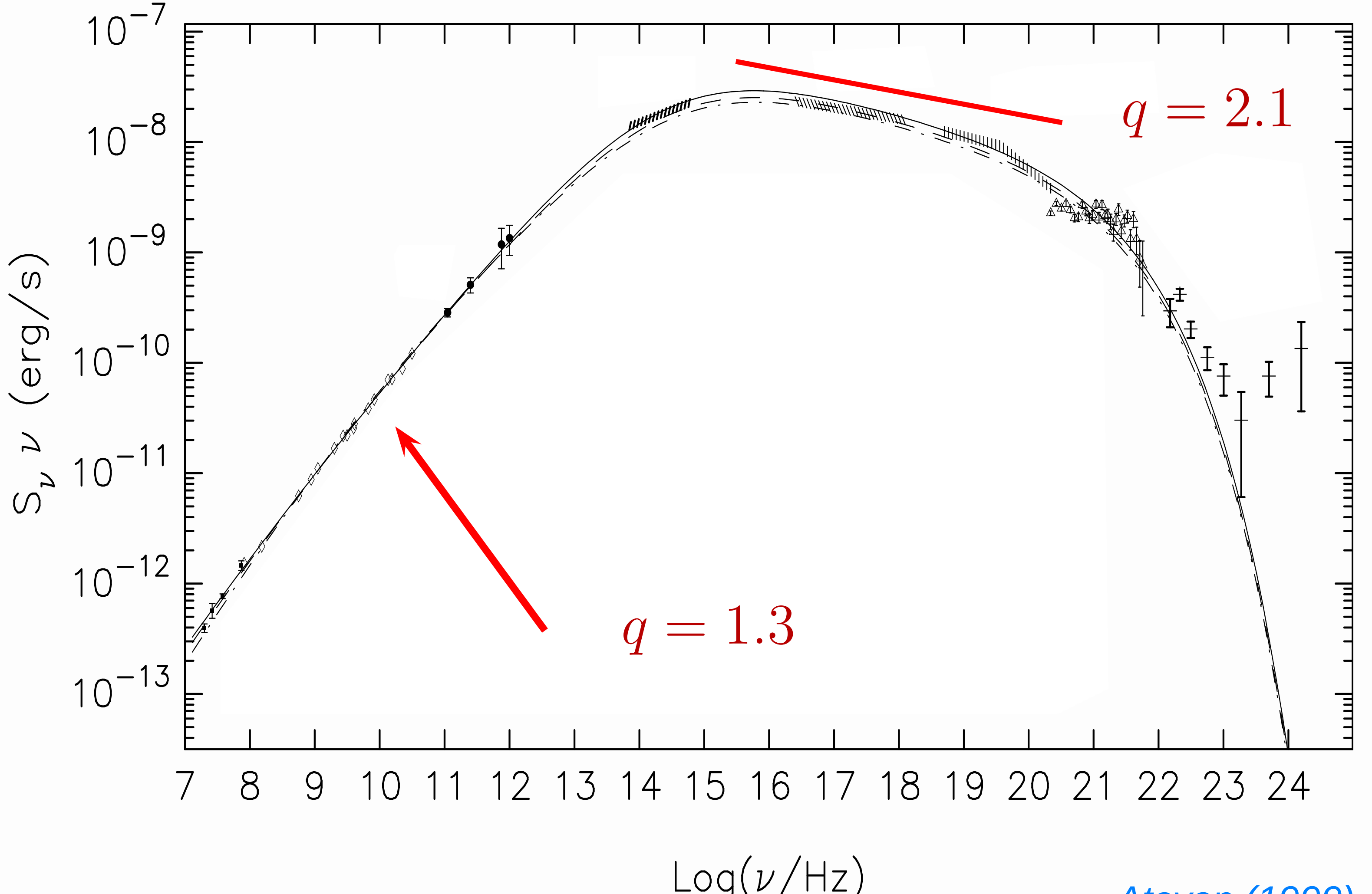

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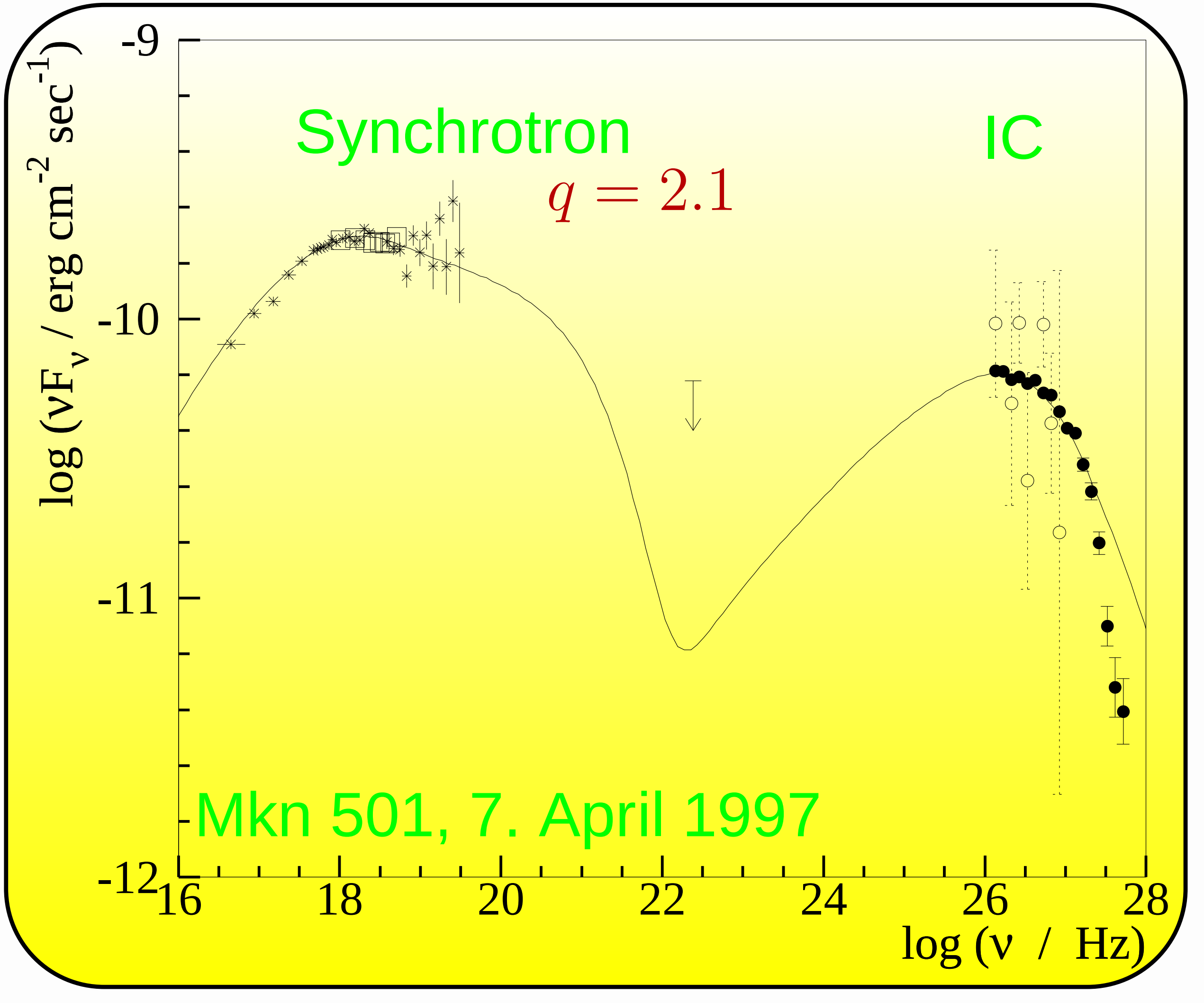
Homogeneous SSC model



Krawczynski et al (2000)

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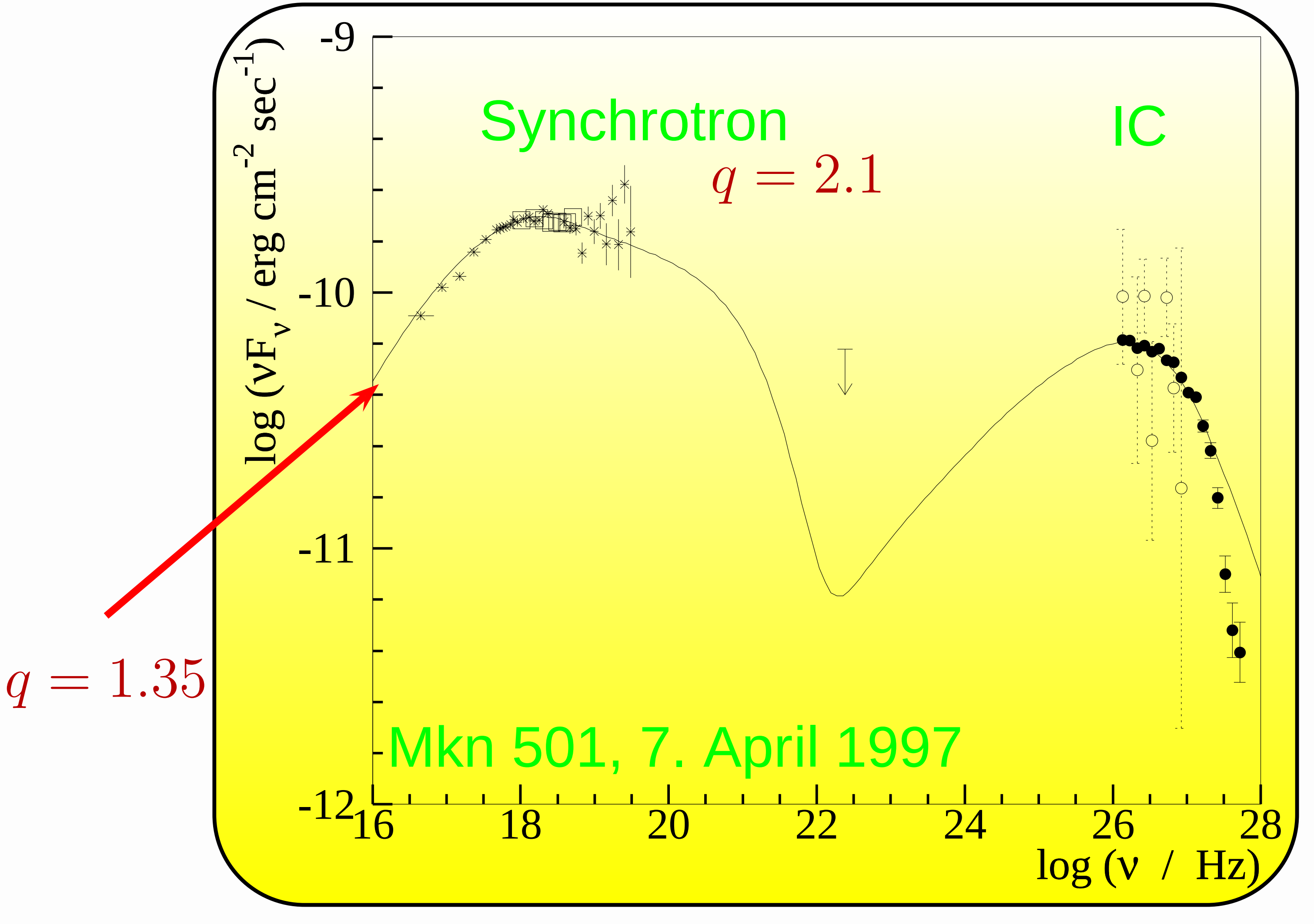

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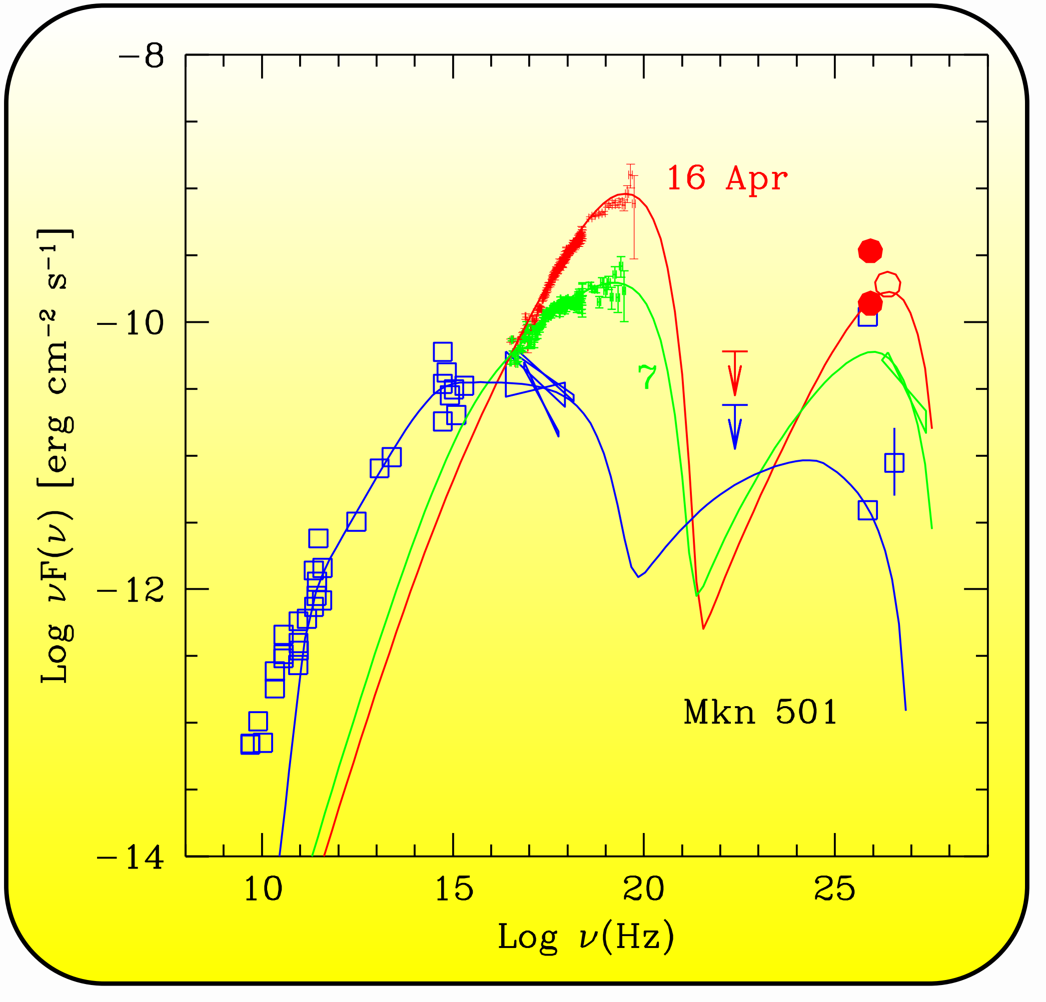
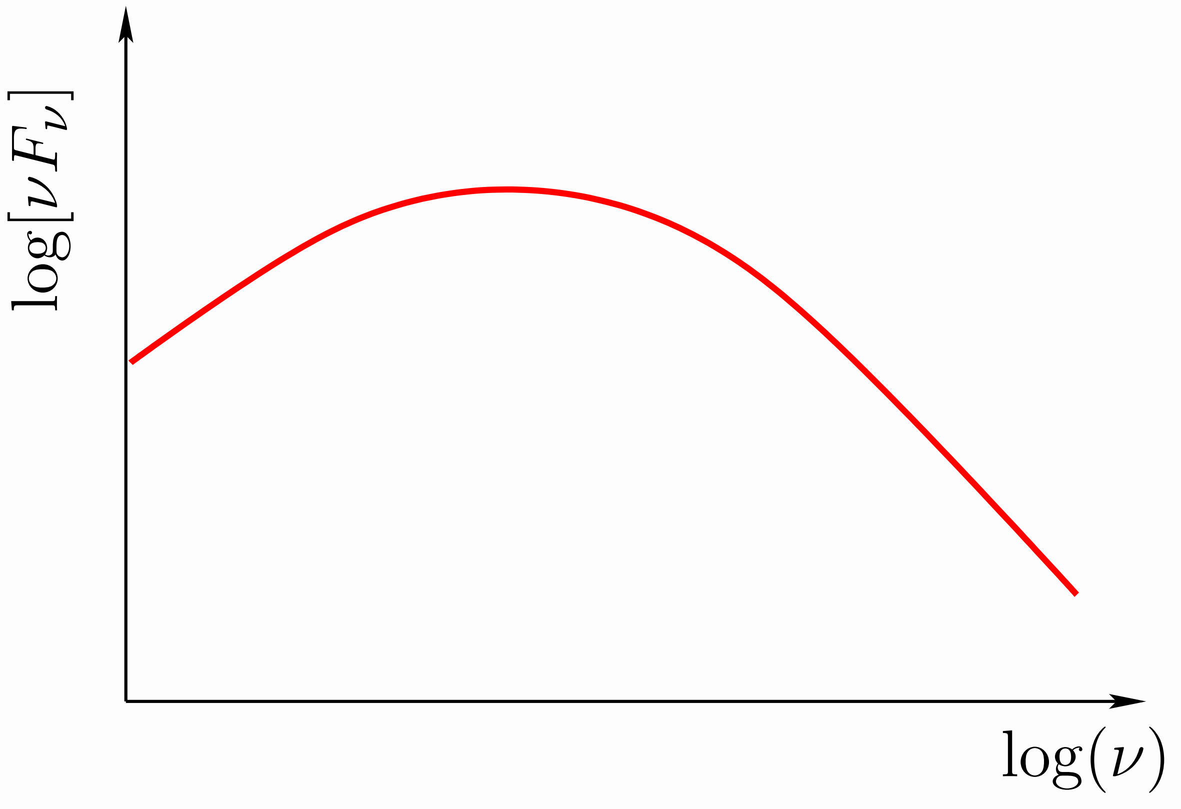


Pian et al (1999)

Injection problem?



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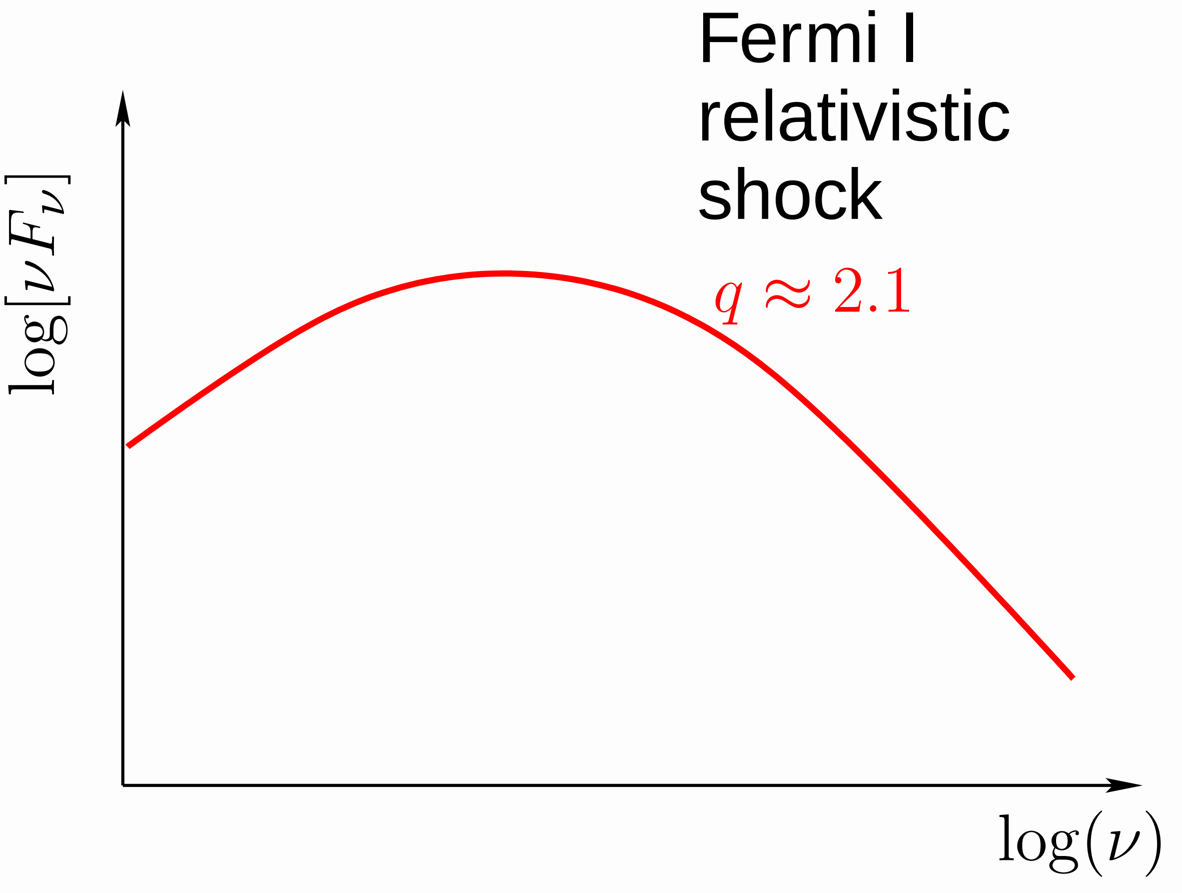

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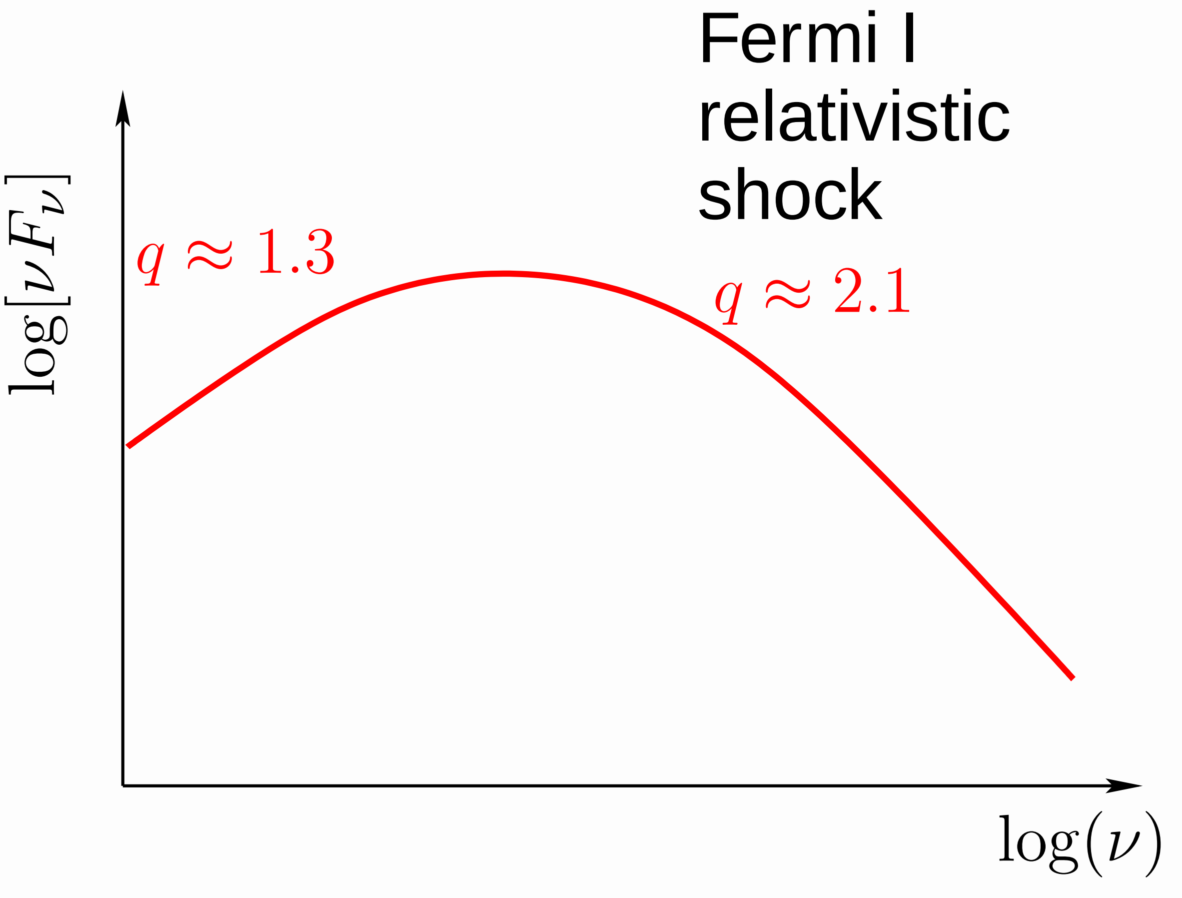

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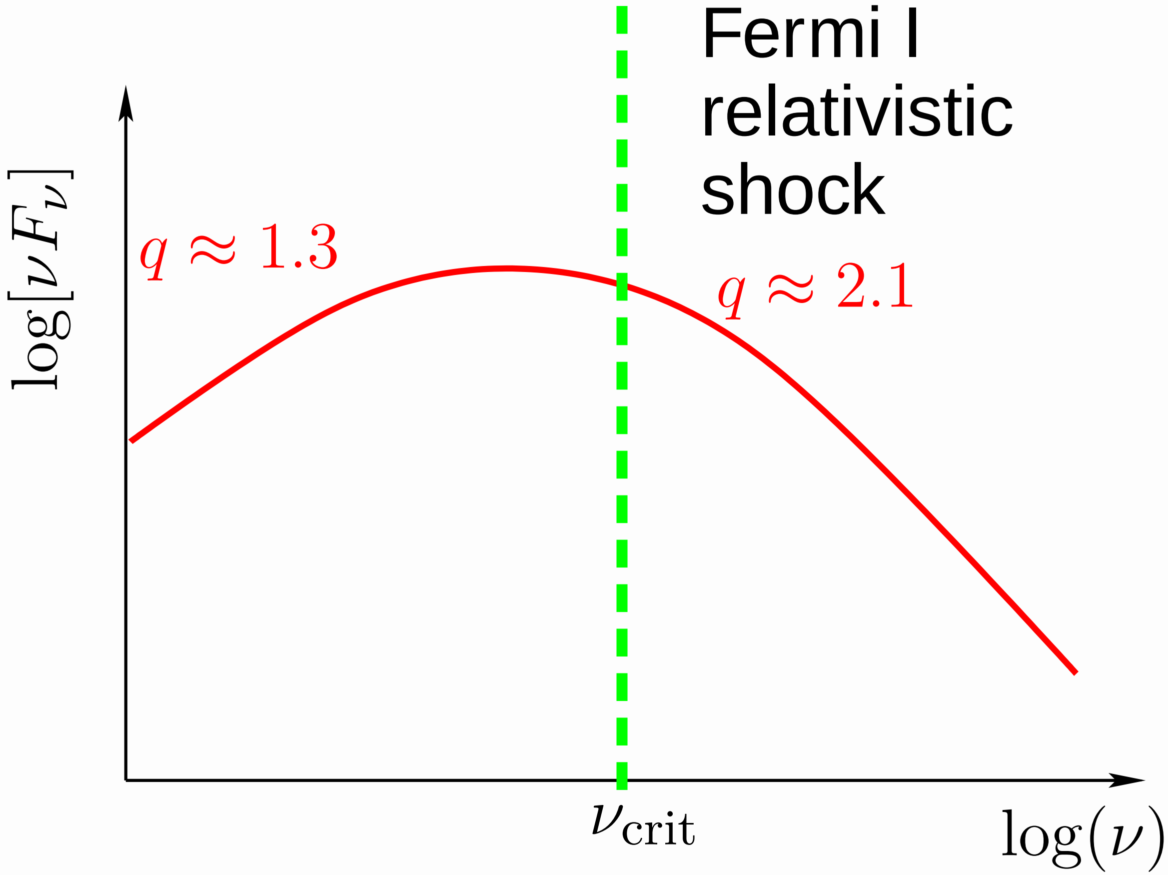

Shock width
$\approx$ gyro radius

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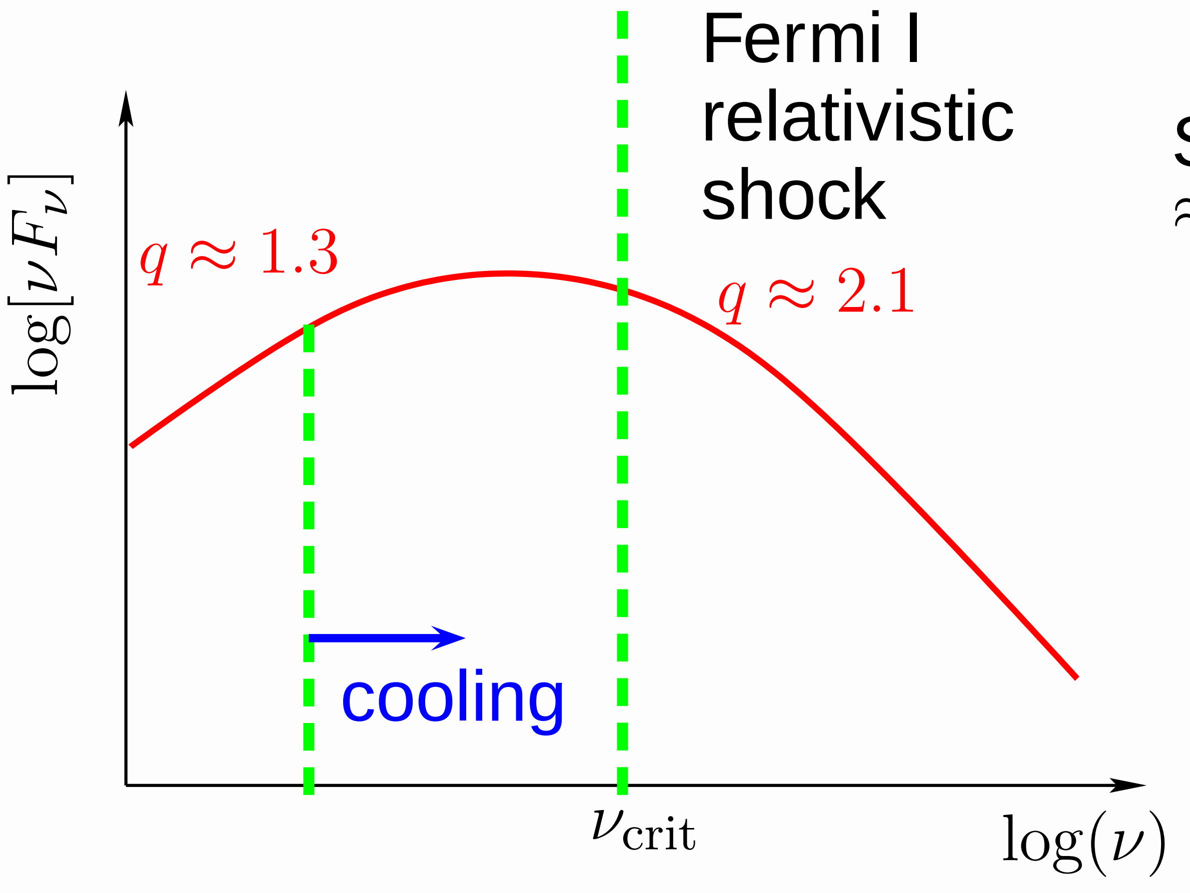

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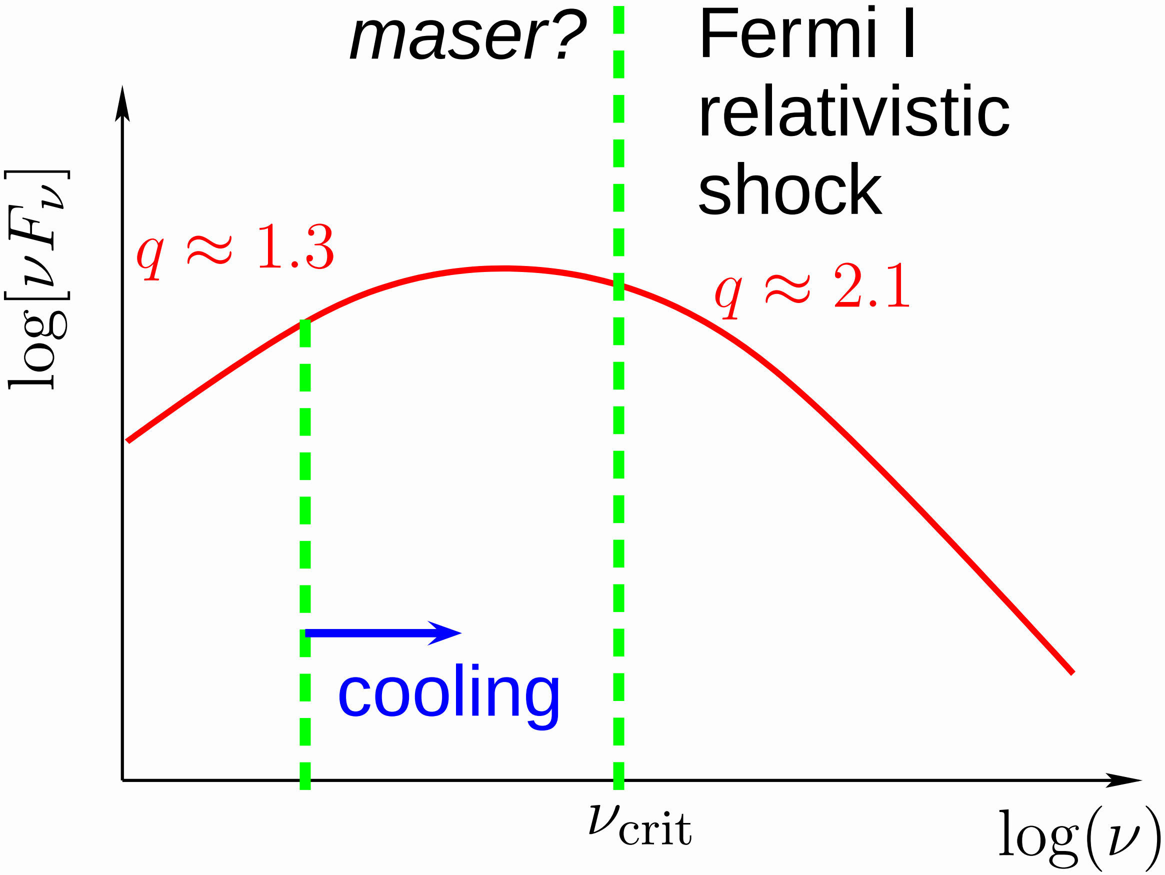

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resonant cyclotron absorption ($p - e^+$)?

Hoshino et al 1992

Amato 2004

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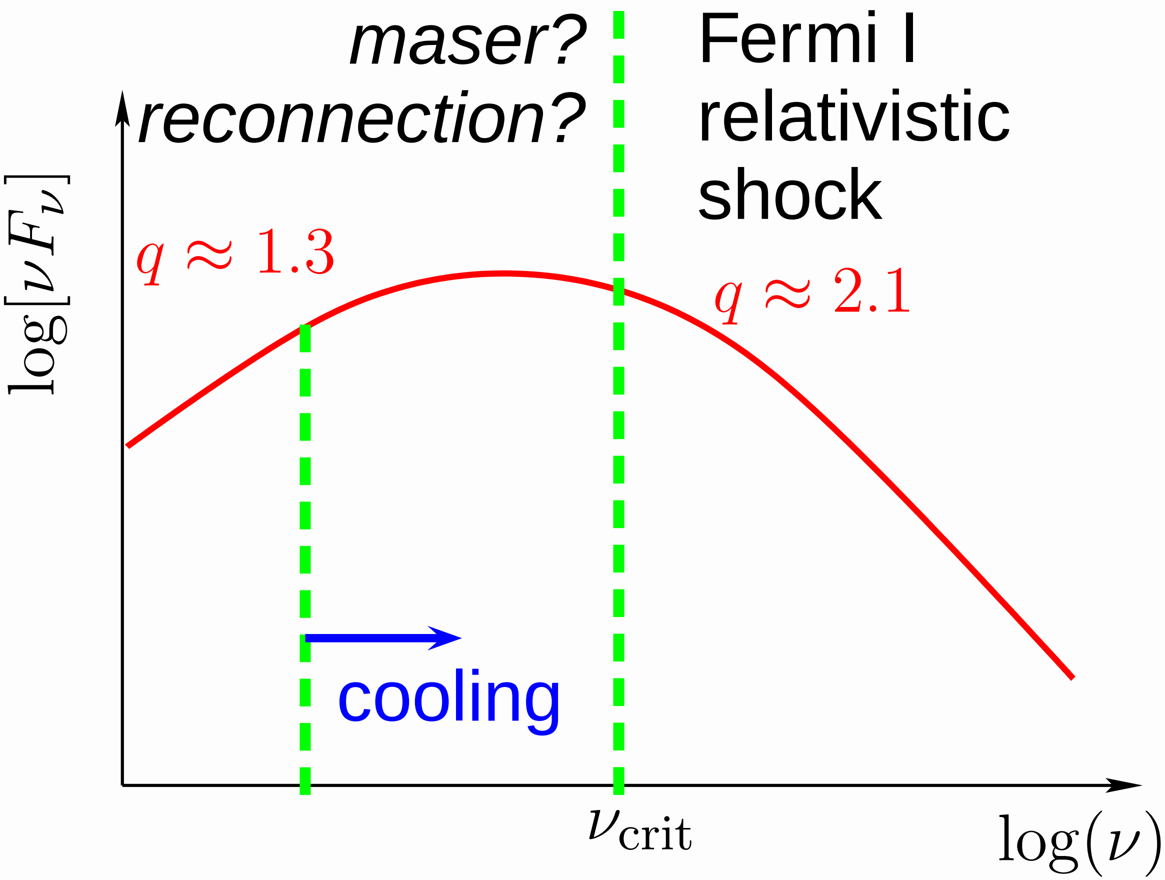

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current sheets

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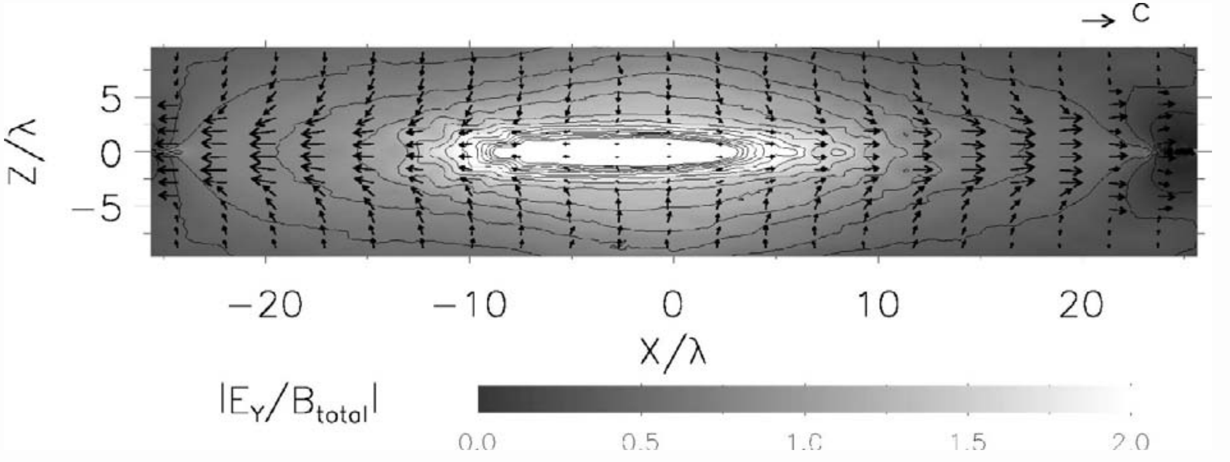

Collisionless relativistic reconnection

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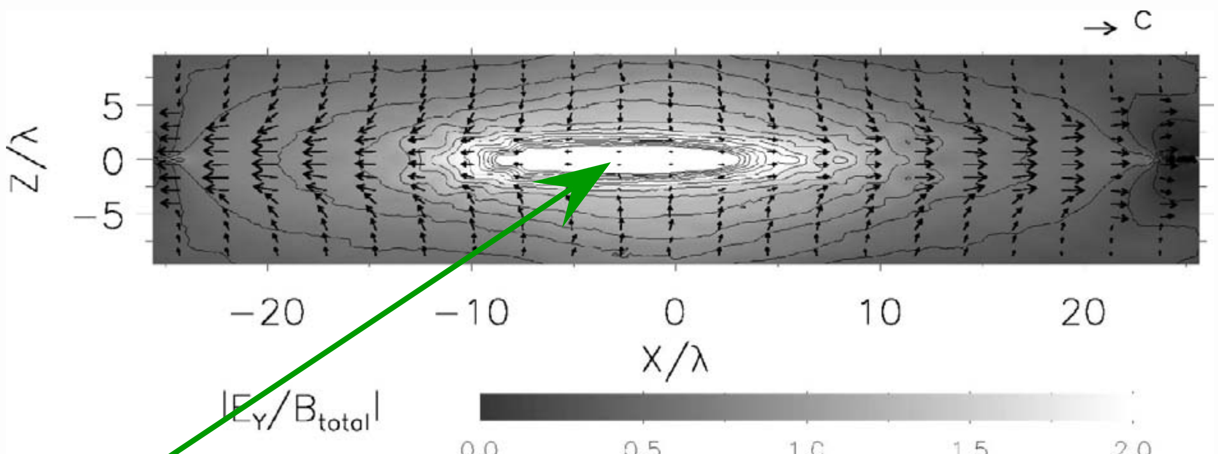

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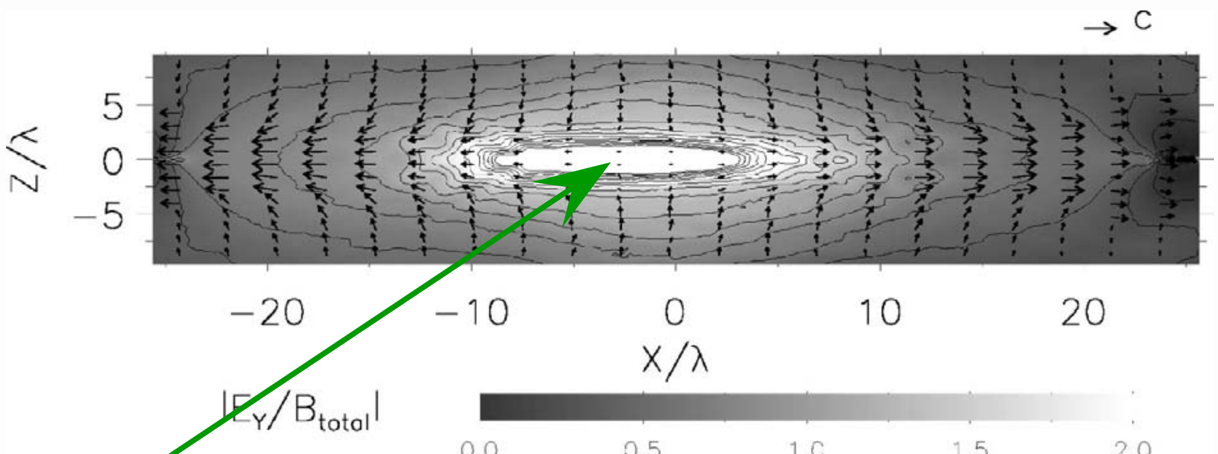

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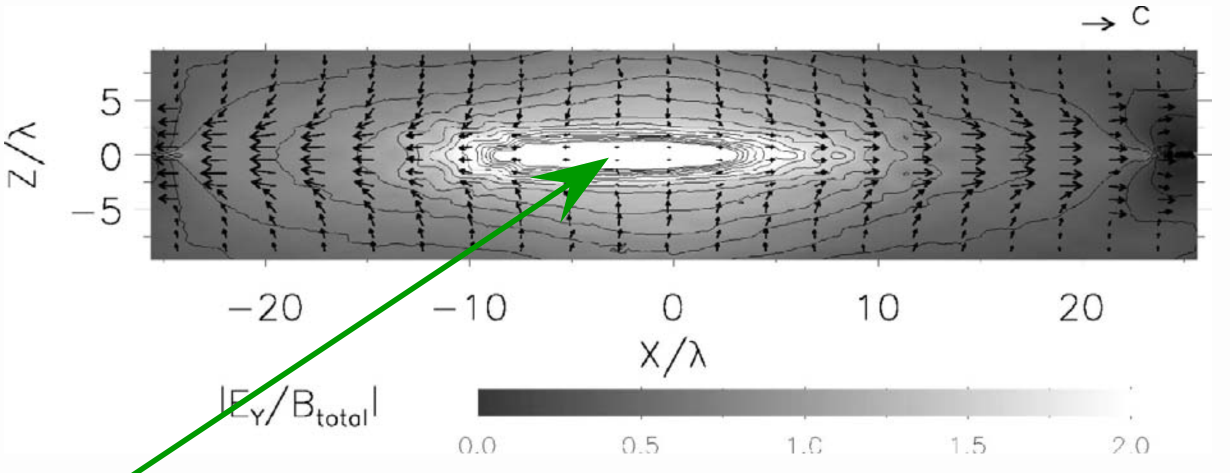

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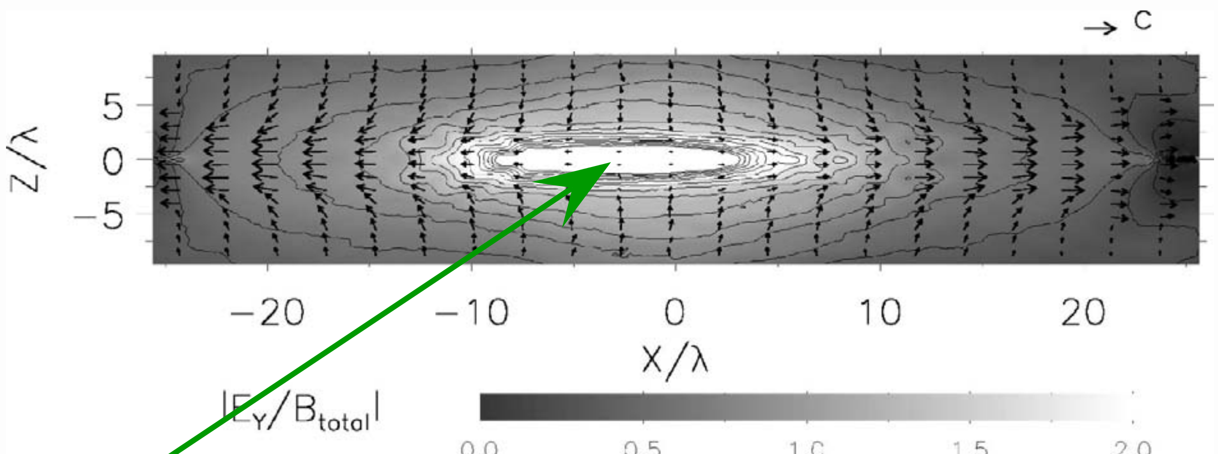

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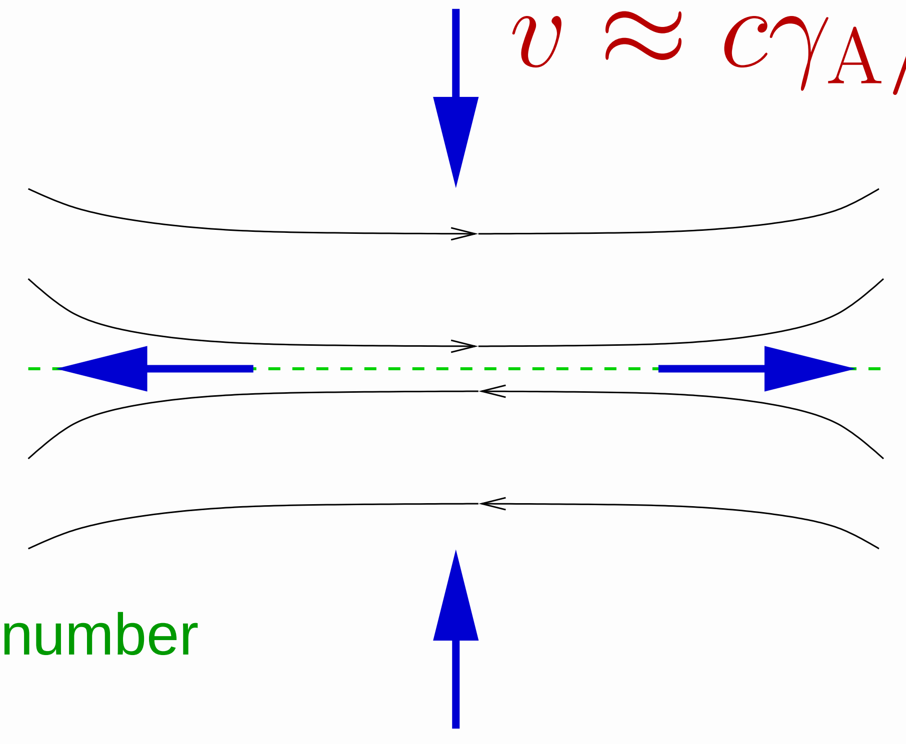
$q = 1$ (uncooled)

Resistive relativistic reconnection

Lyutikov & Uzdensky 2003

$$v \approx c\gamma_{\mathrm{A}}/R^{1/2}$$



$$\gamma \approx \gamma_{\mathrm{A}}^2$$

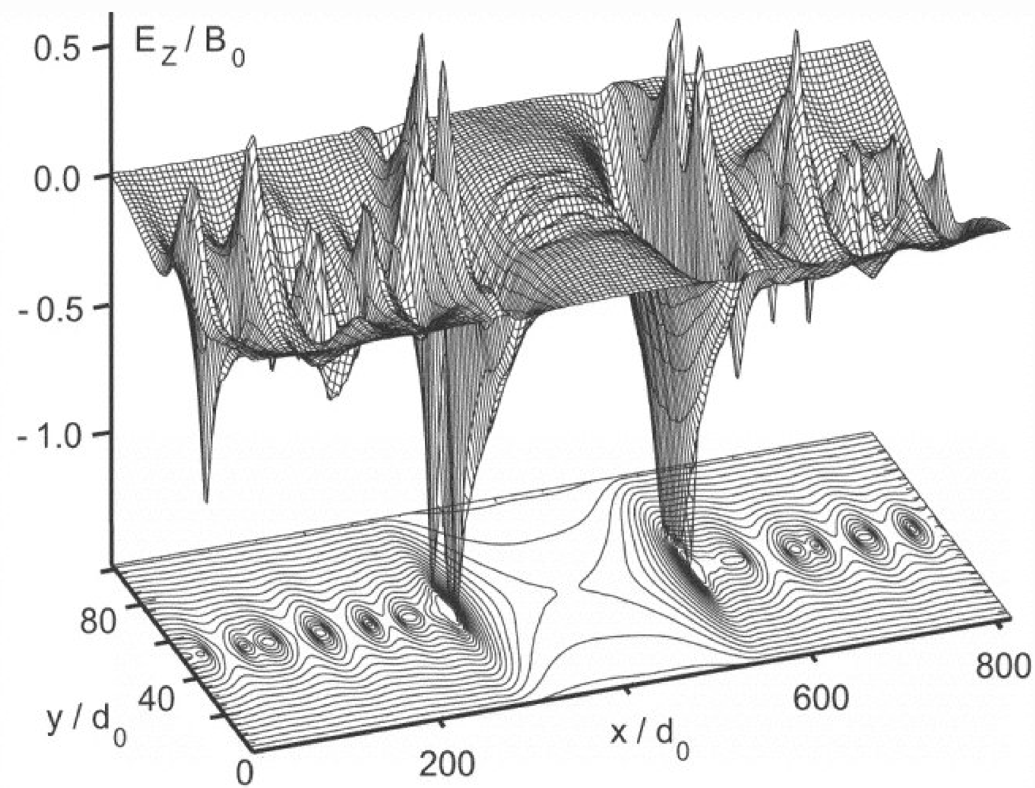
$R =$ Reynolds number

Magnetization parameter $\sigma = B^2/(4\pi w) \approx \gamma_{\mathrm{A}}^2 \gg 1$
Nonrelativistic inflow for $\sigma \ll R$.

Additional regimes with relativistic inflow possible. . .

P.I.C. simulations

Jaroschek et al (2004)



- pair plasma

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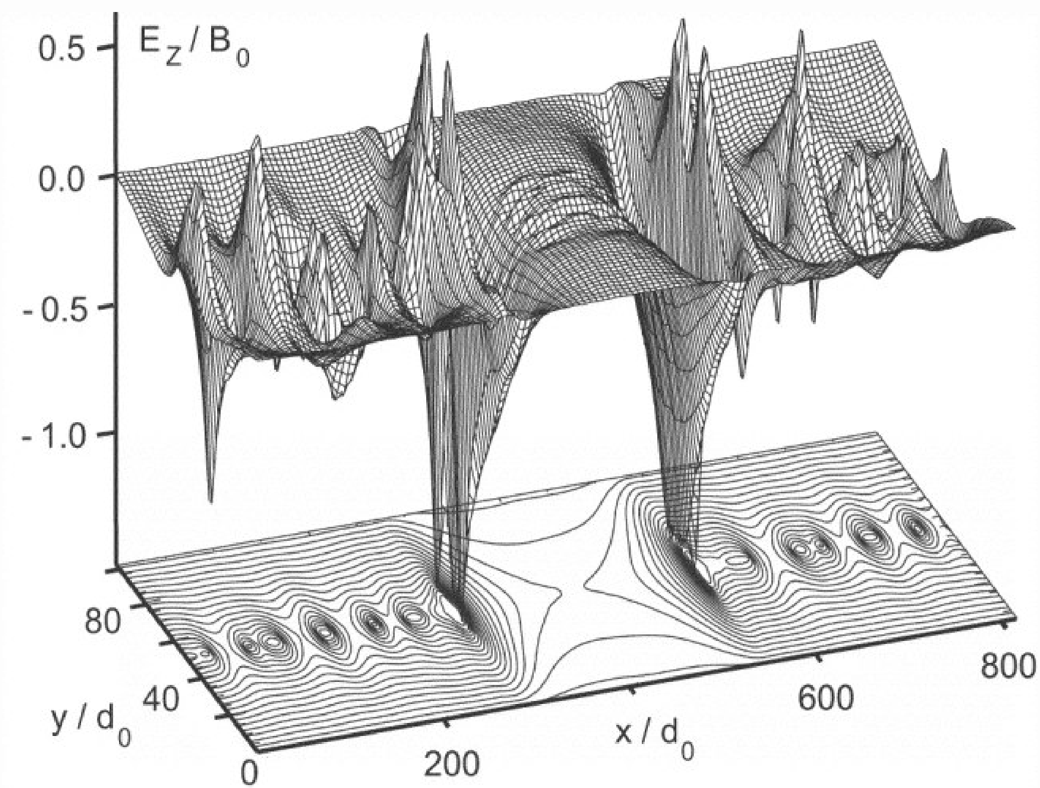

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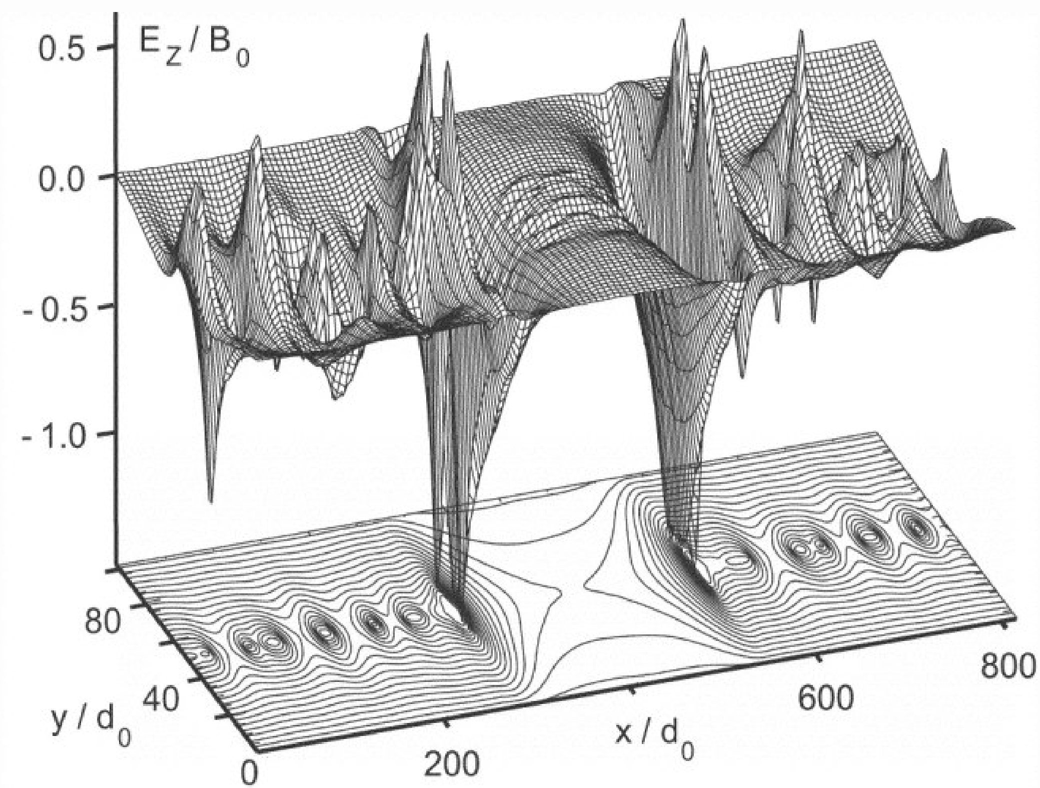

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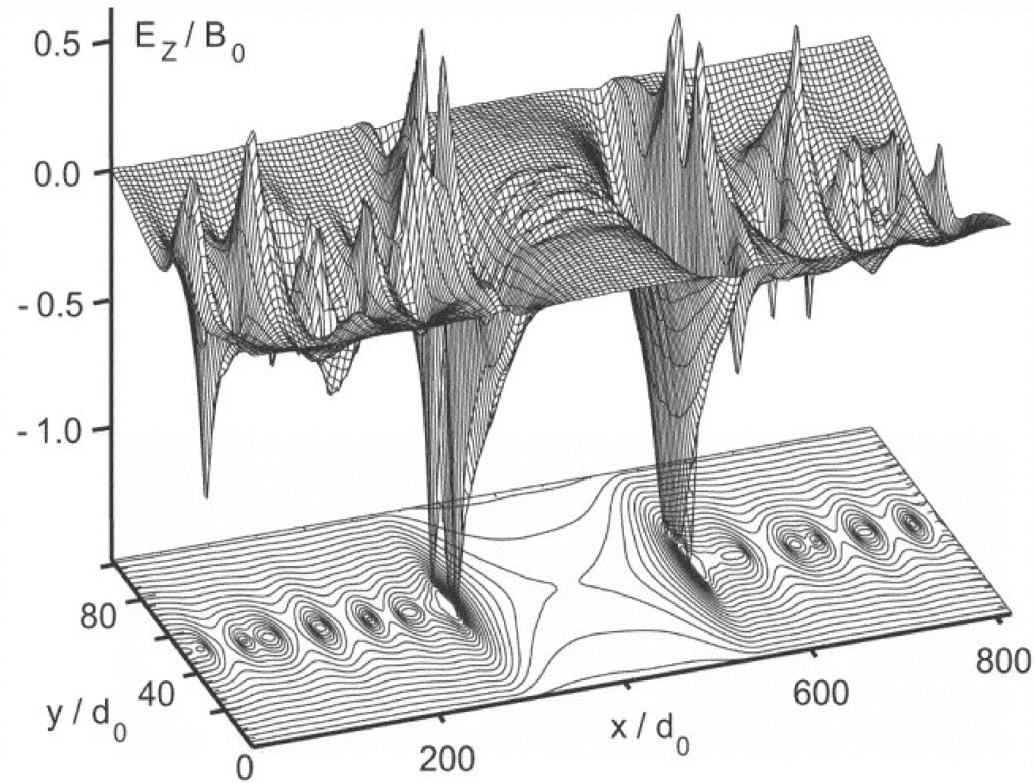

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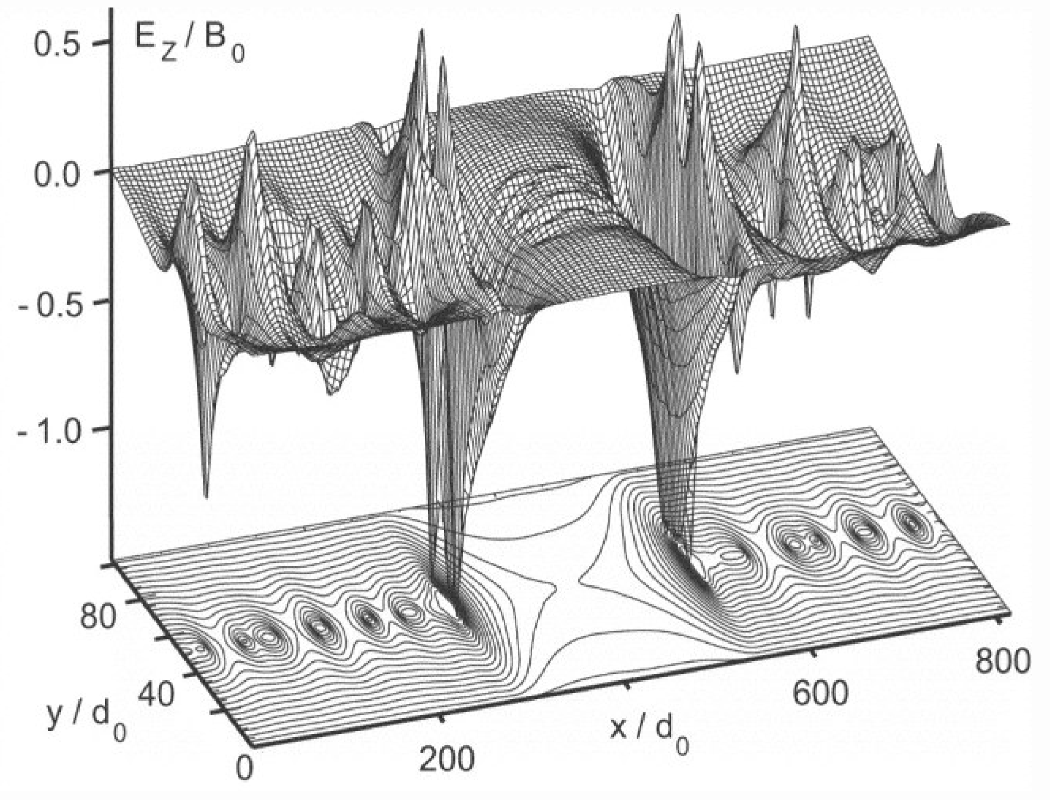

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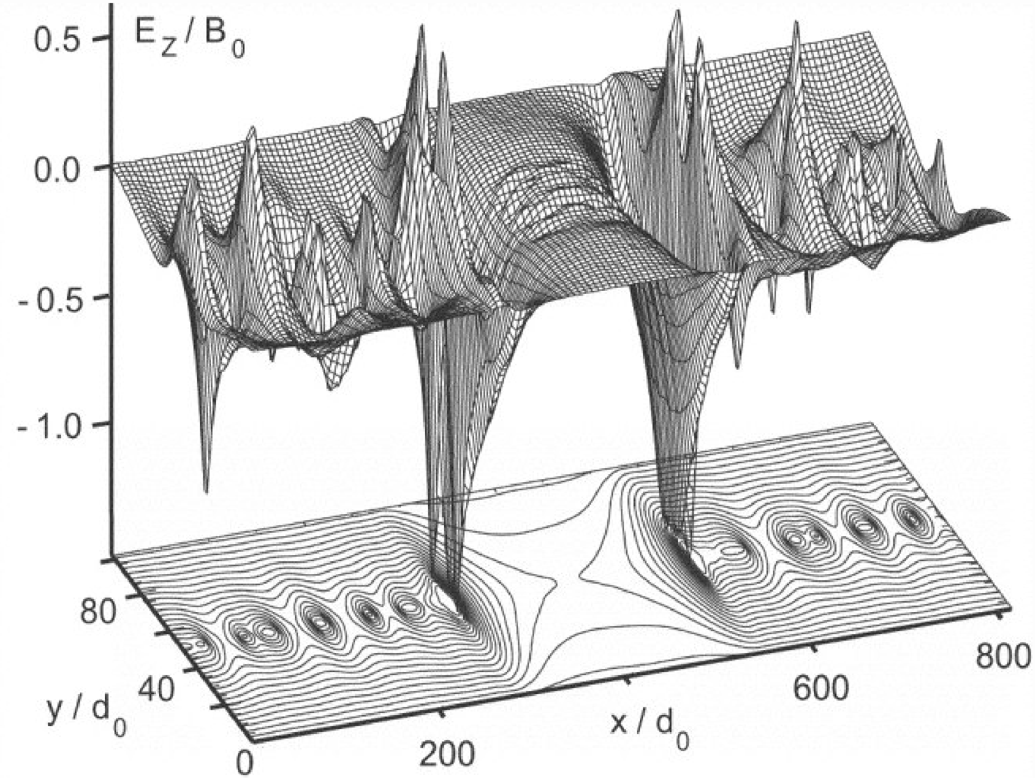

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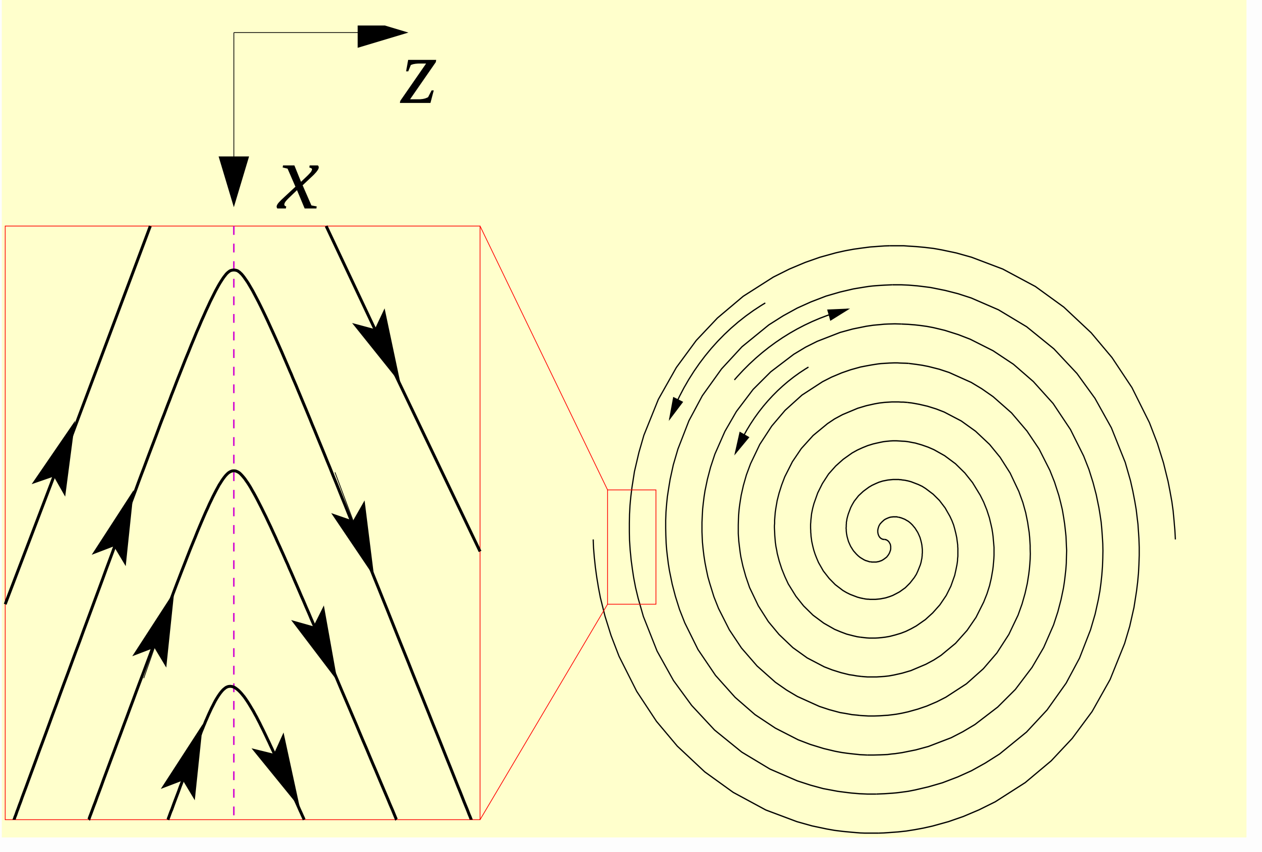
- $|E/B| > 1$ in extended zone

Sheets in the striped wind

Relativistic current sheets

J.K., *Phys. Rev. Letts.* (2004)



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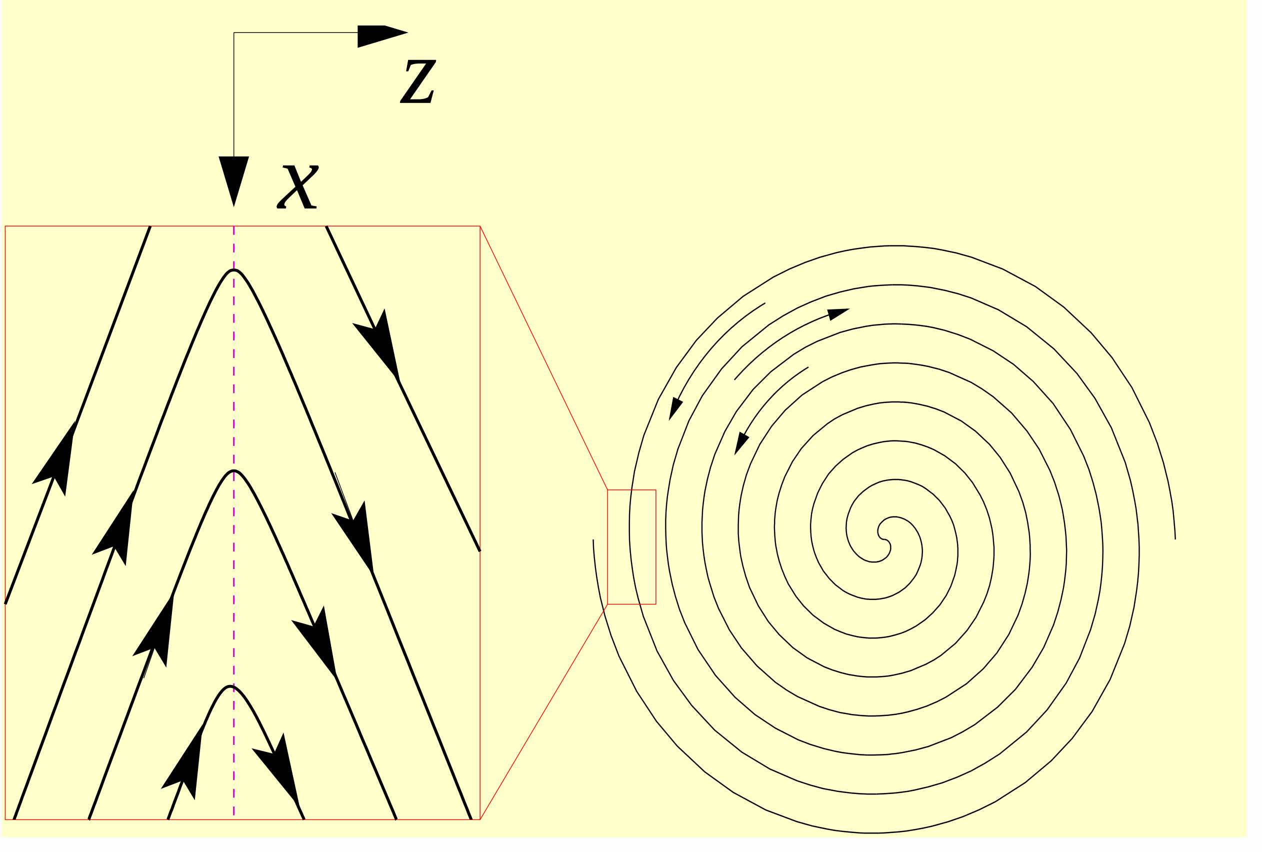

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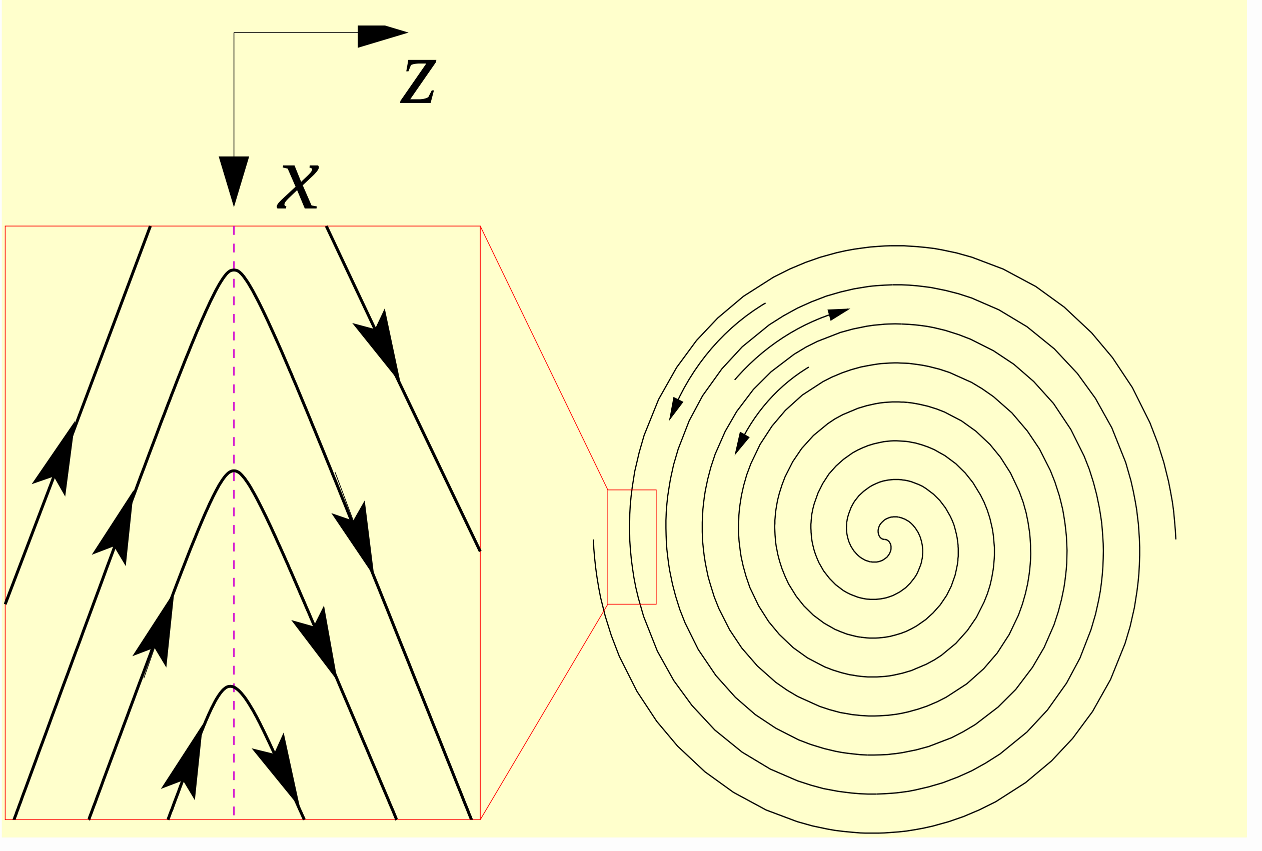

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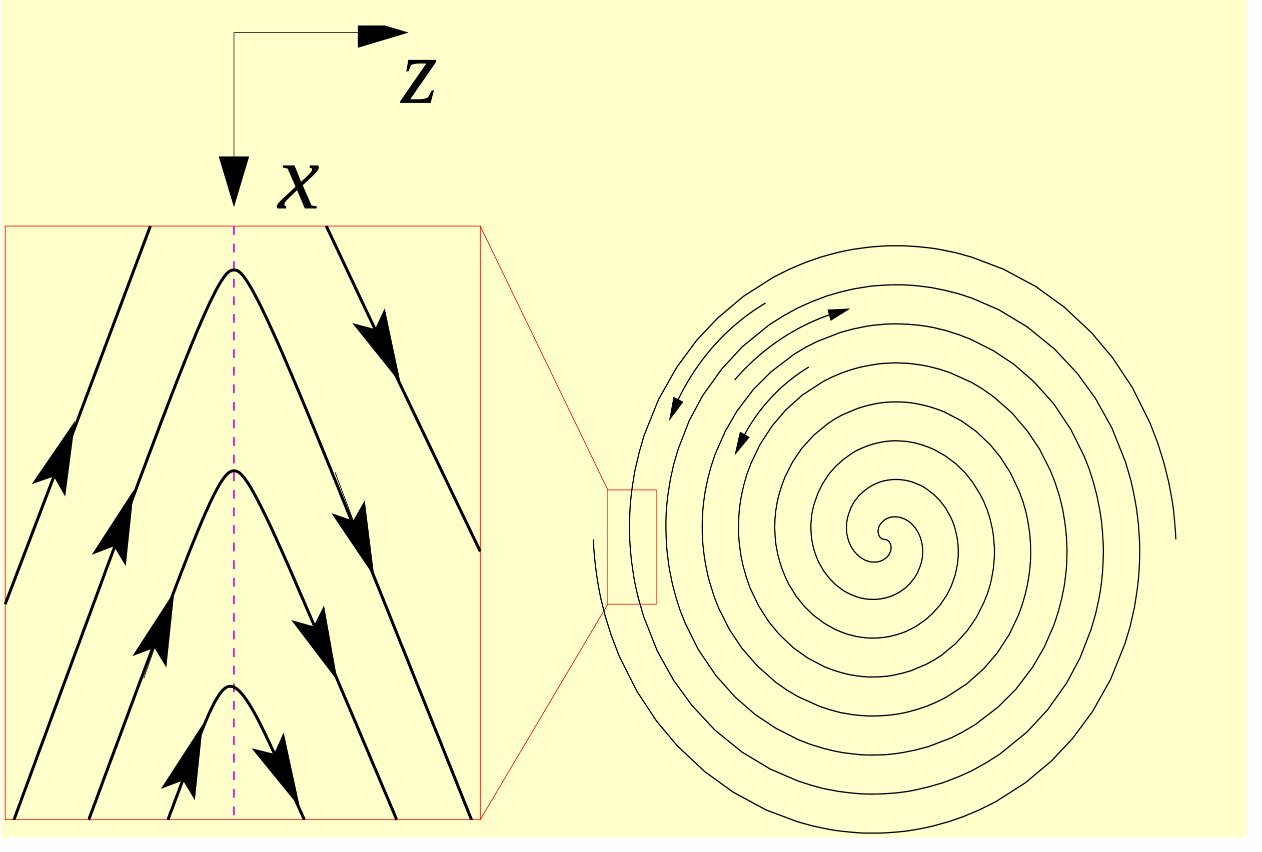

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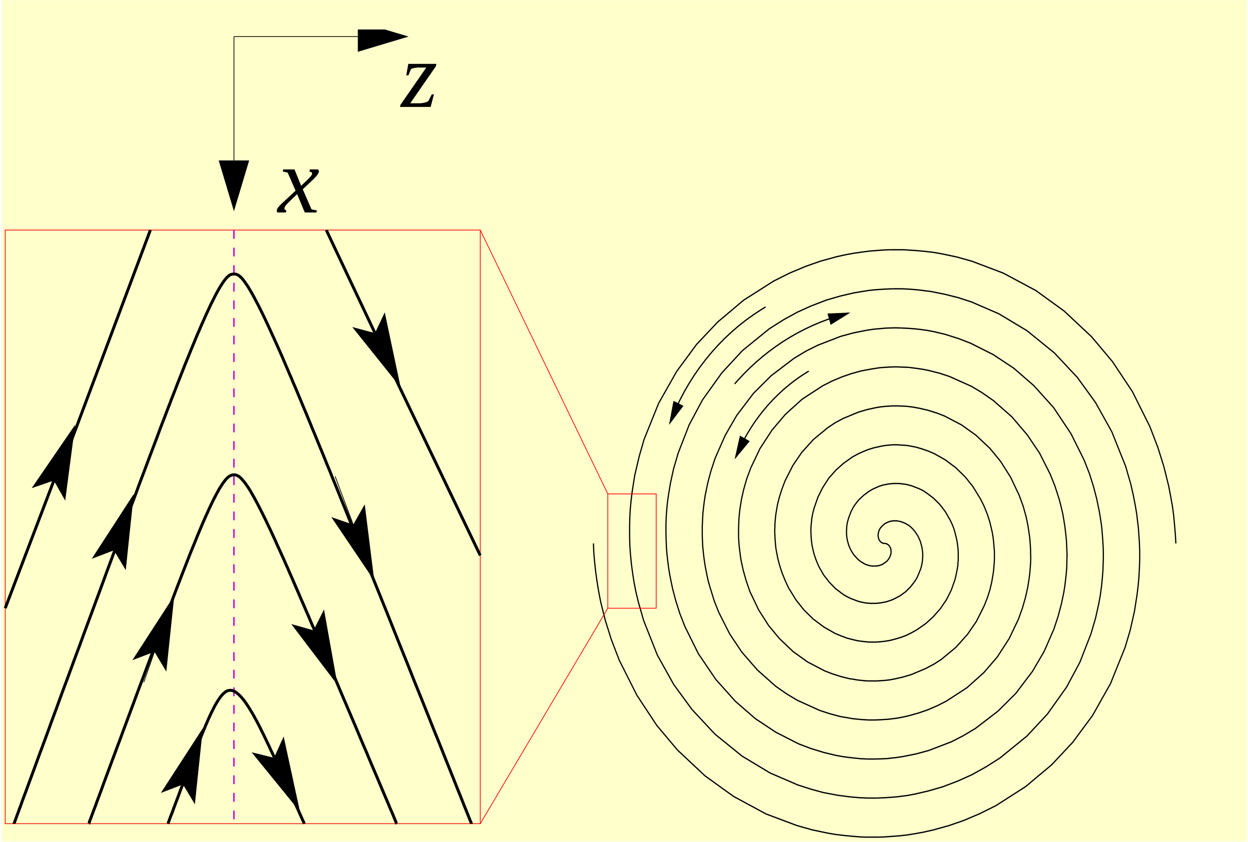

Maximum energy

$\gamma \approx 2\sigma$ (pair plasma)
$\gamma \approx \sigma M/m$ (e – p)

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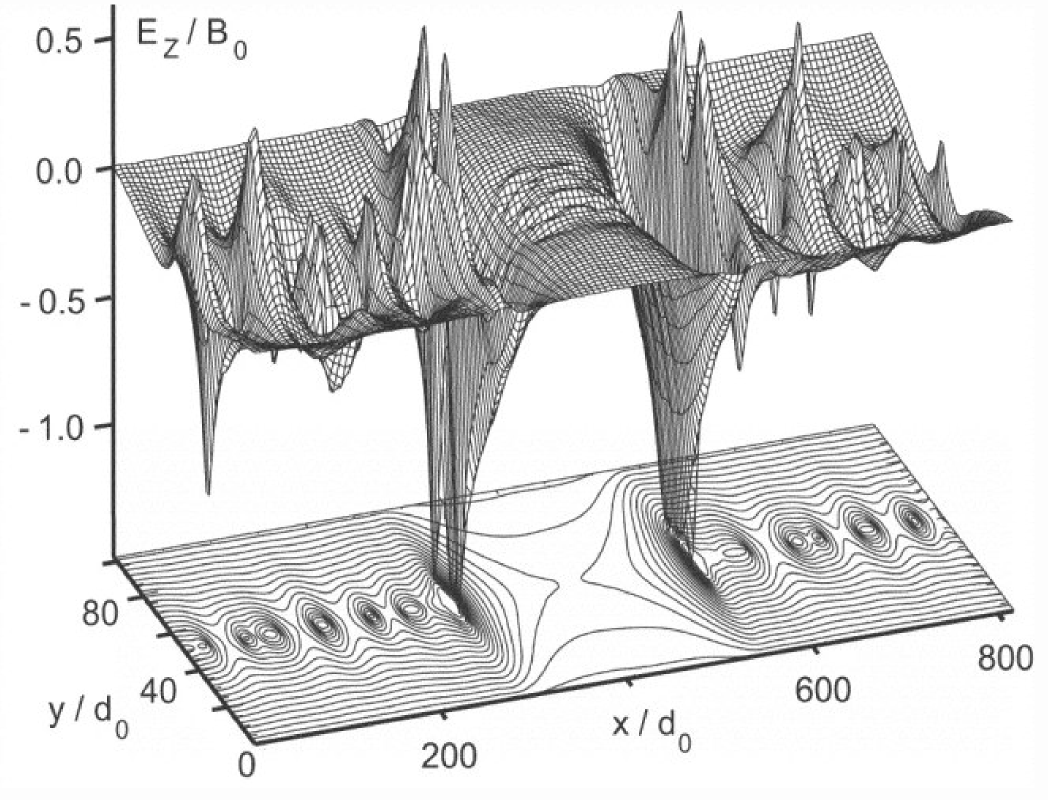
Hybrid mechanism?



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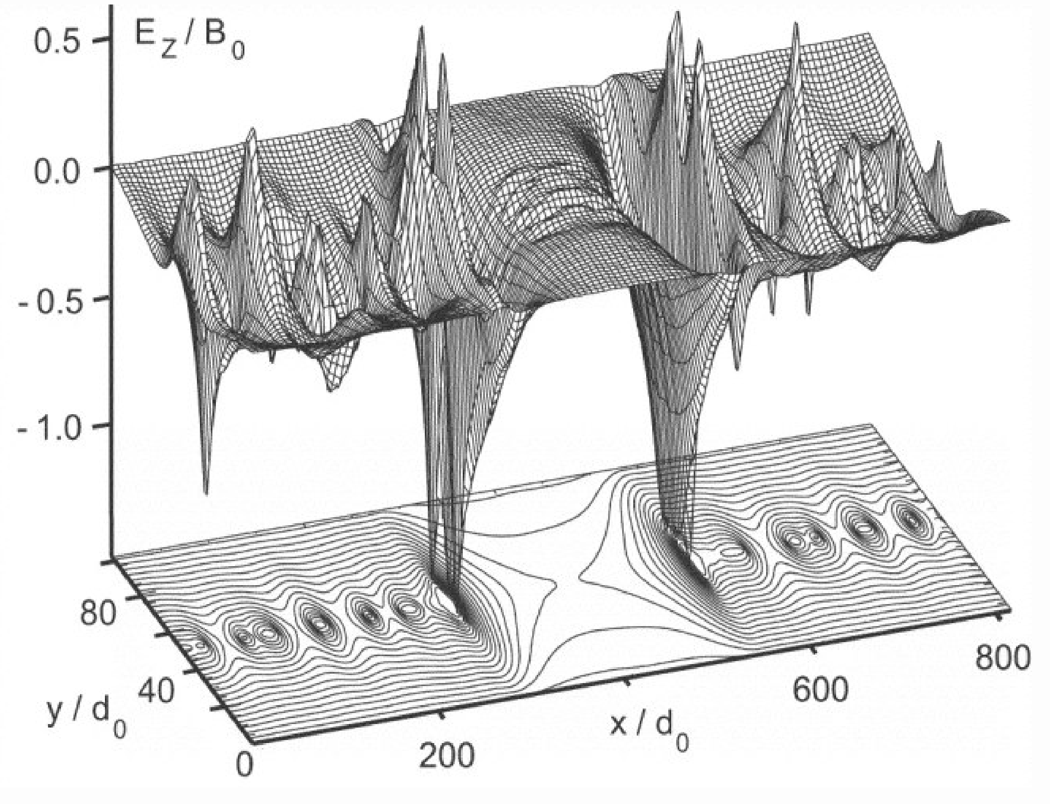

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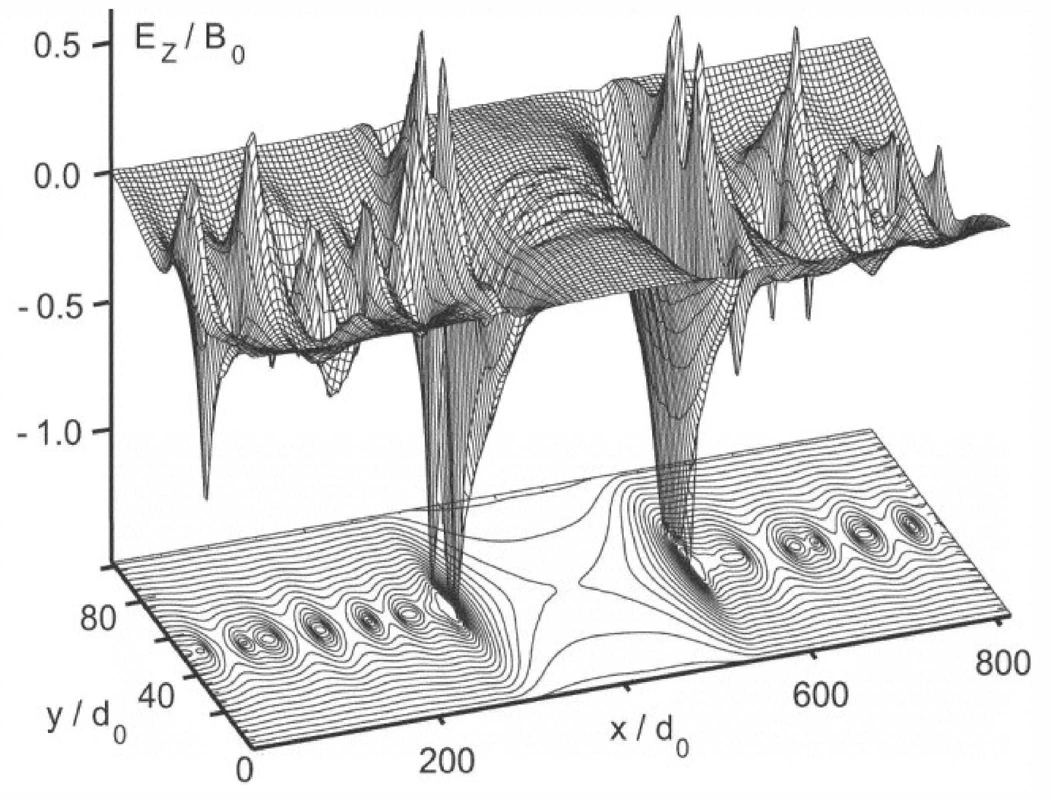

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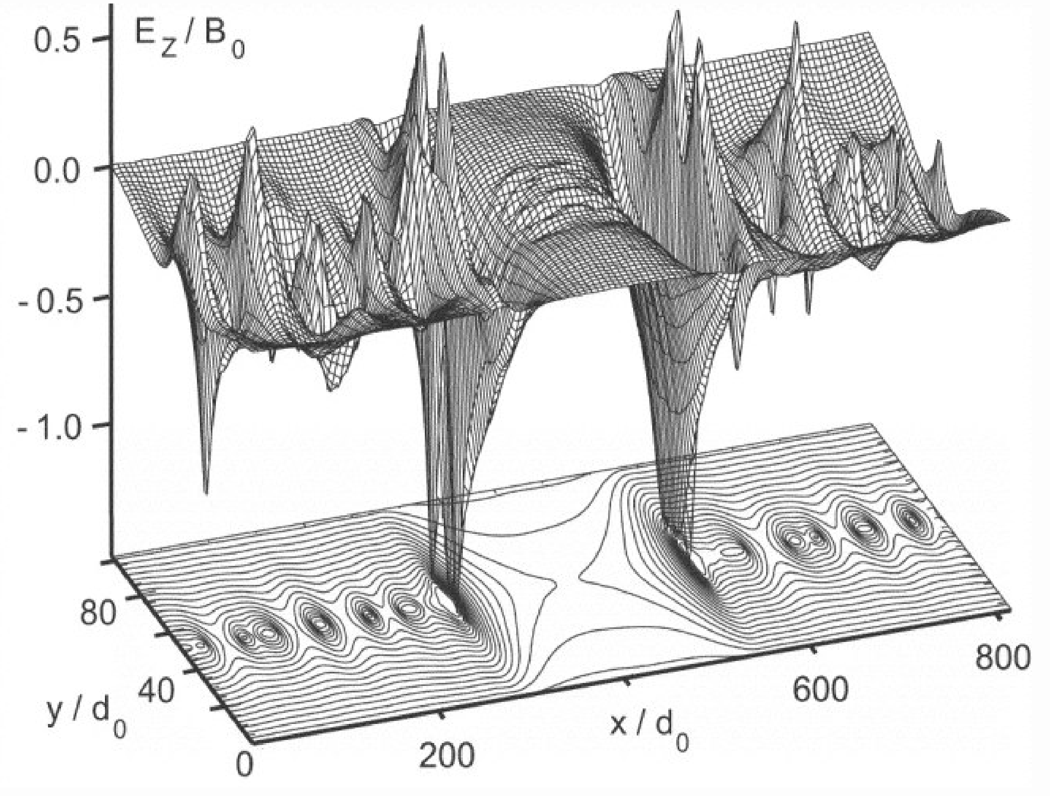

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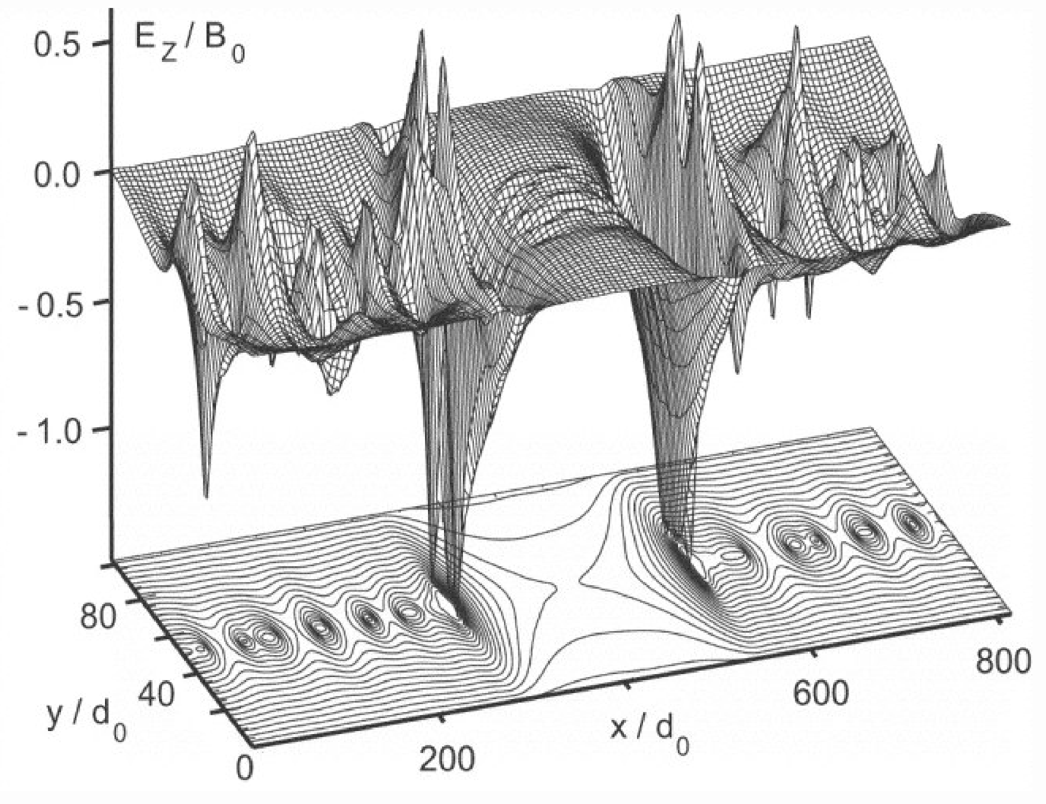

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