Jitter radiation from highly relativistic shocks

Mikhail Medvedev (KU)

Collaborators: Luis Silva, Ricardo Fonseca, M. Fiore, M. Marti, *and others from the Plasma Simulation Group* (IST, Portugal), Warren Mori (UCLA)

Many thanks to: Christian Hededal, Troels Haugboelle, Aake Nordlund (Niels Bohr Institute, Copenhagen, Denmark)

Relativistic Jets: AGNs, micro-Quasars, GRBs

Dec. 16, 2005

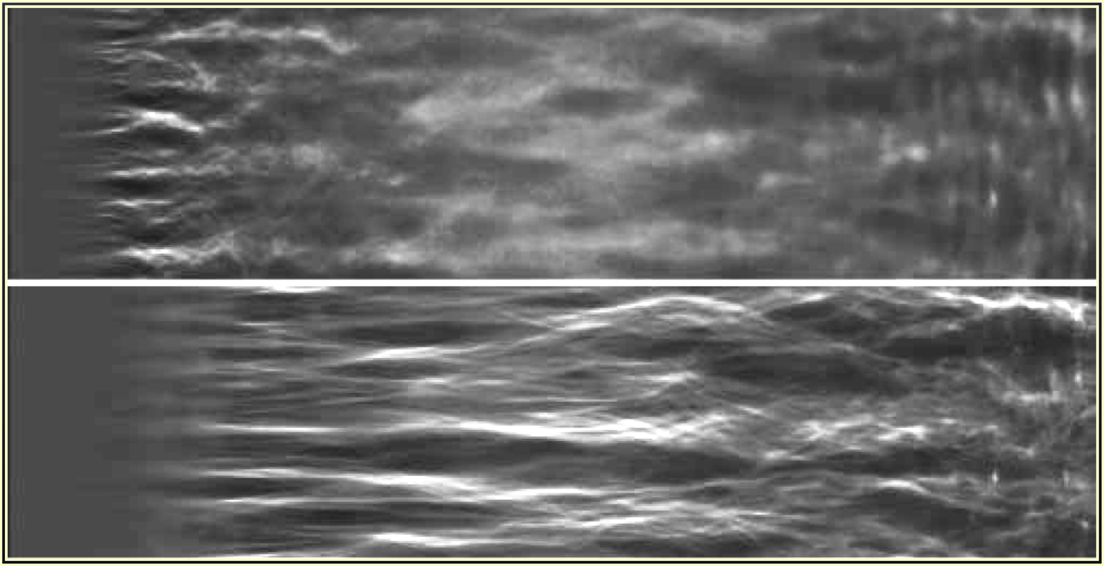
Outline

Details: talk by Luis Silva
Here: essential facts

- Introduction:
  Shock microphysics, Weibel turbulence, particle acceleration
- Radiation production at shocks
- Spectral variability
- Shock emission in jets
- Polarization of radiation
- Summary

Relativistic *e^-p* shock

Proton density

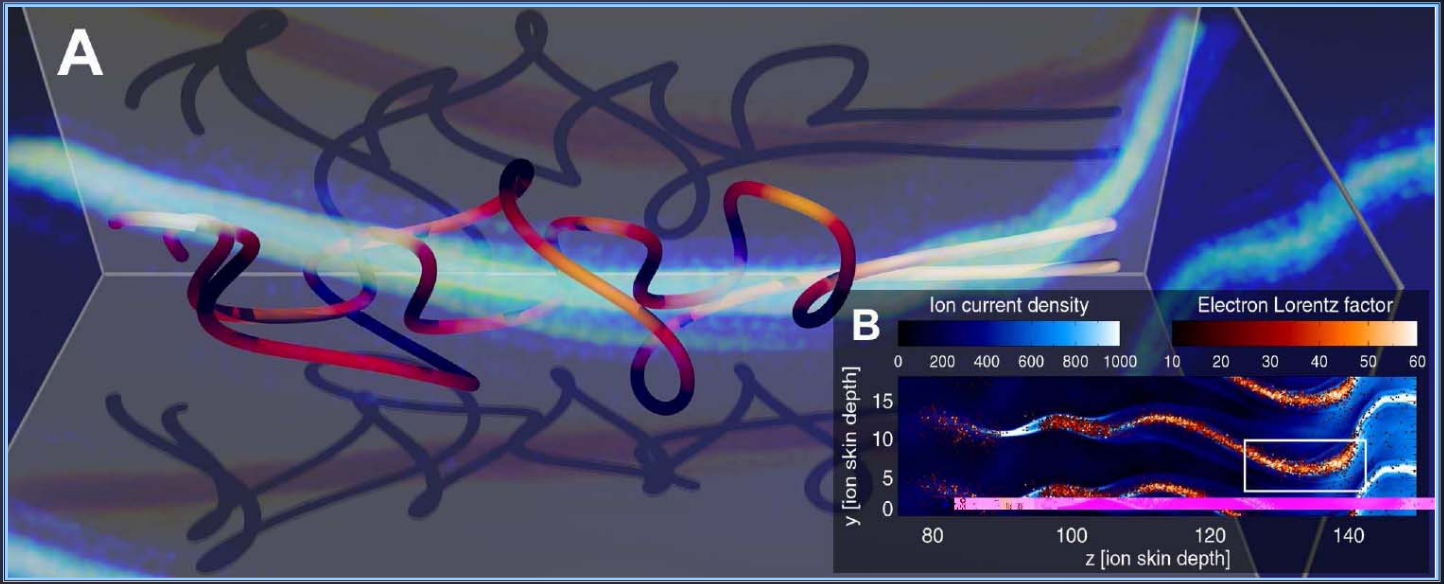


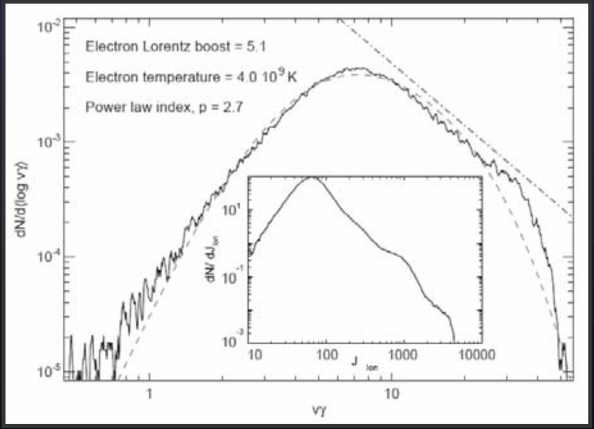
Electron currents

Proton currents

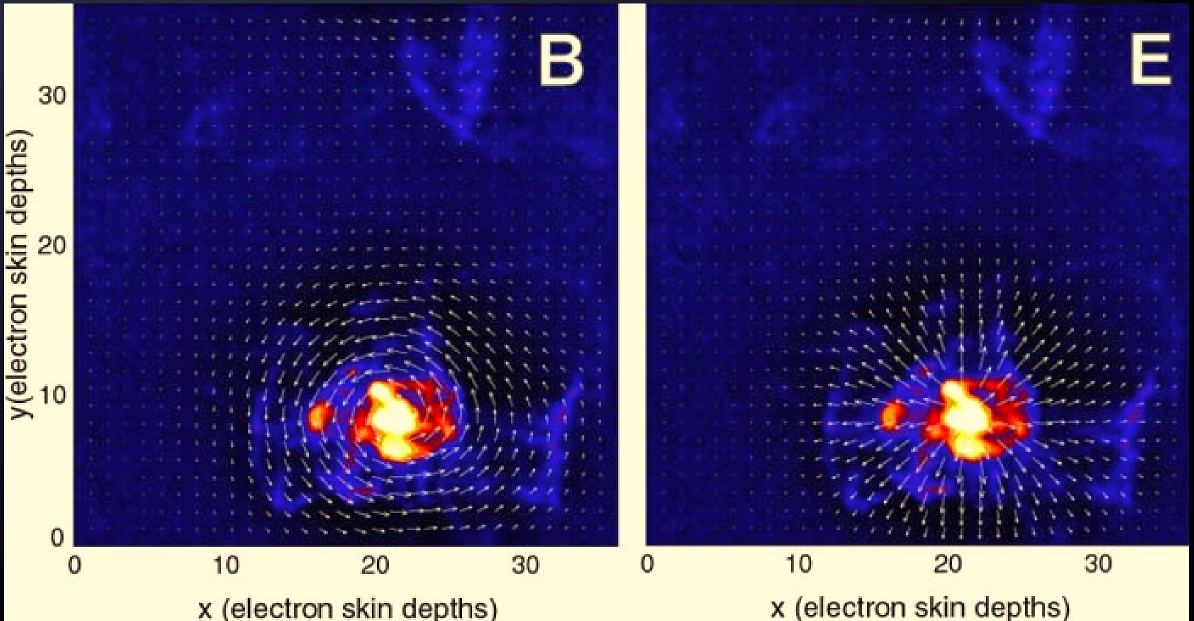
(Frederiksen, et al., 2003)

Particle acceleration $e^{-}p$





(Hededal, et al, 2005, PhD)



Outline

Radiation from small-scale random fields

- Introduction:
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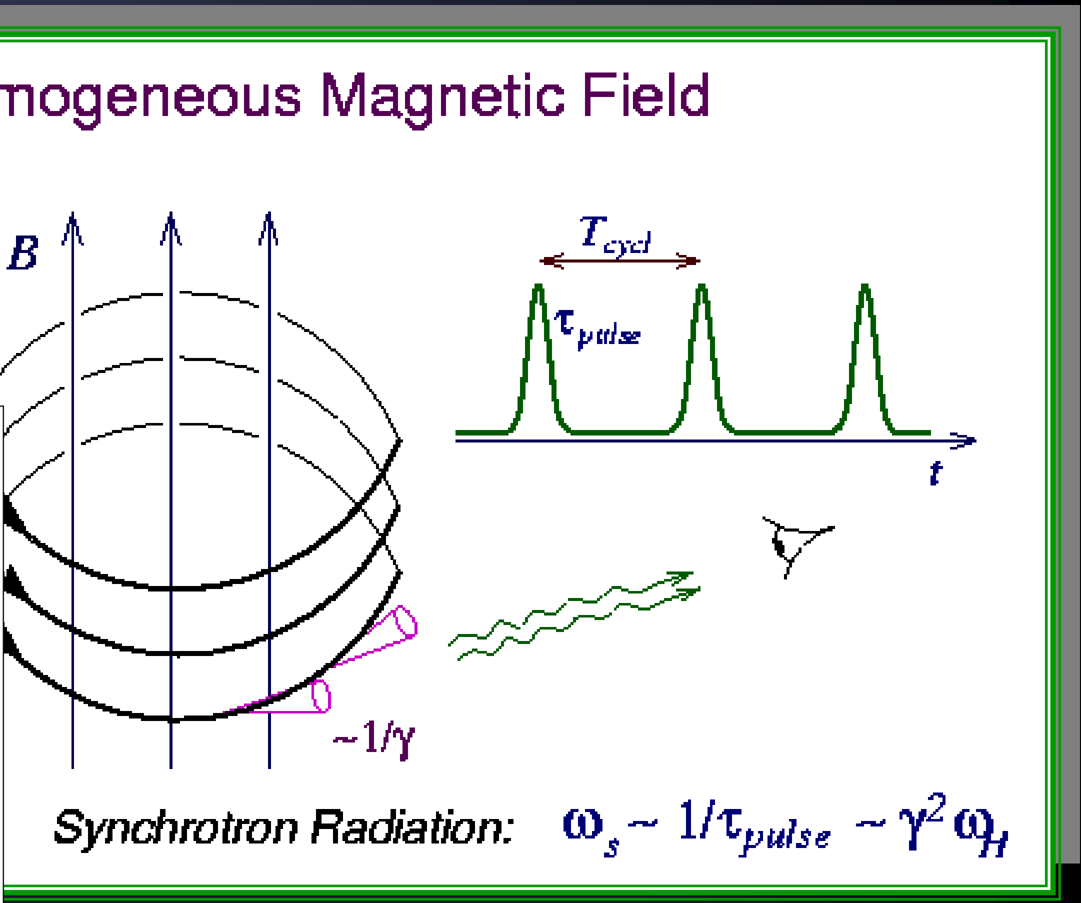
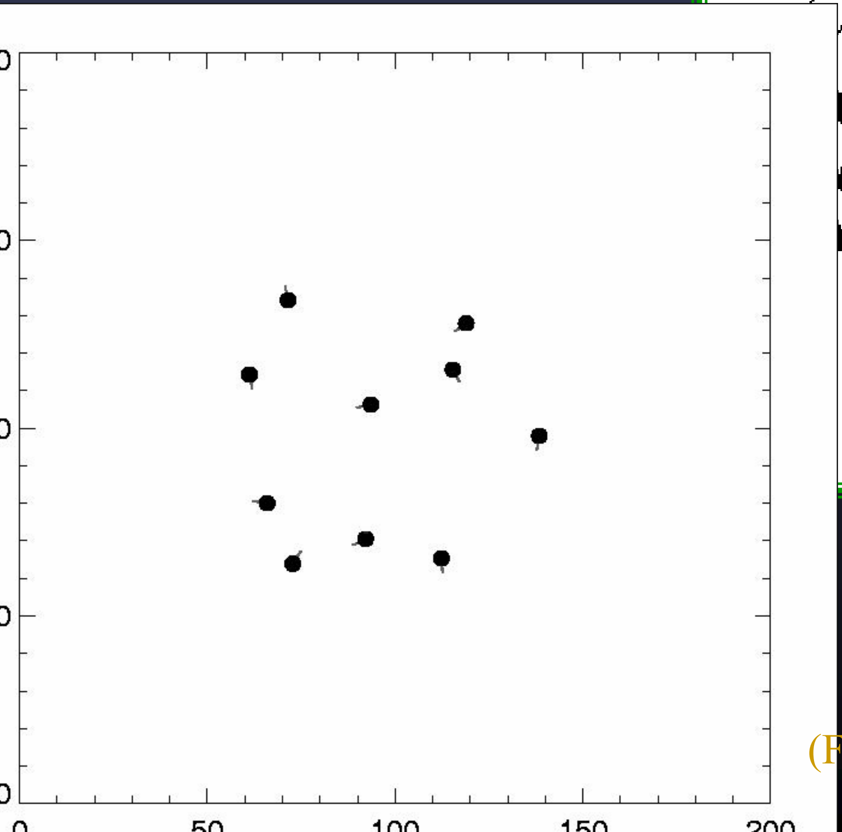
Synchrotron Radiation

$B(r)=B_0=\text{const}$

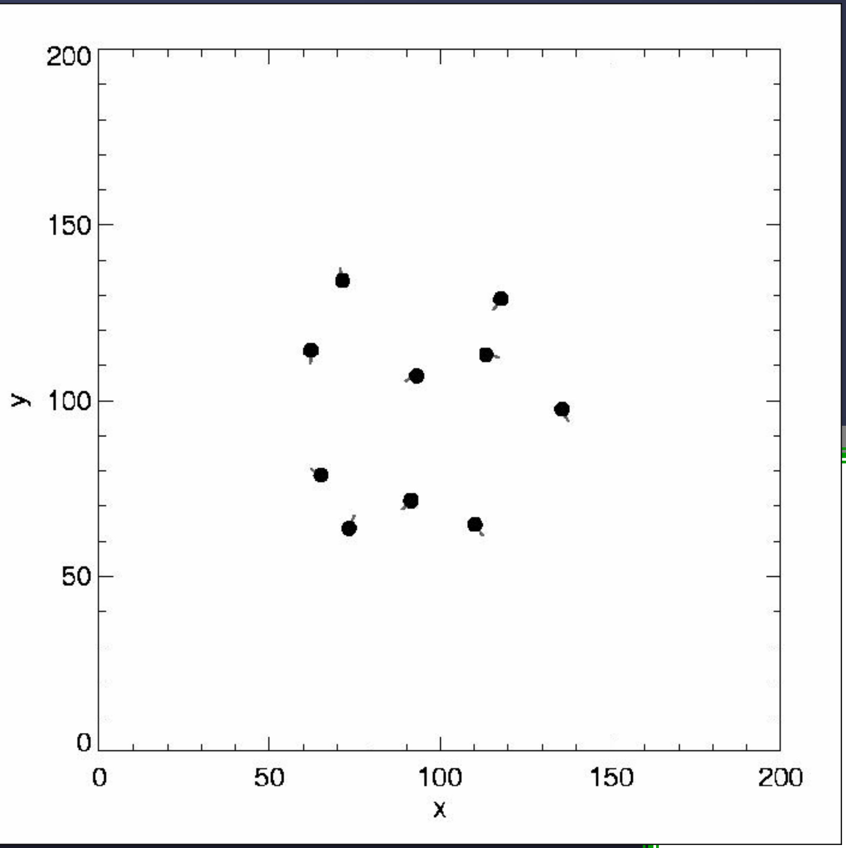
(homogeneous)





(Frederiksen, 2005, PhD thesis)

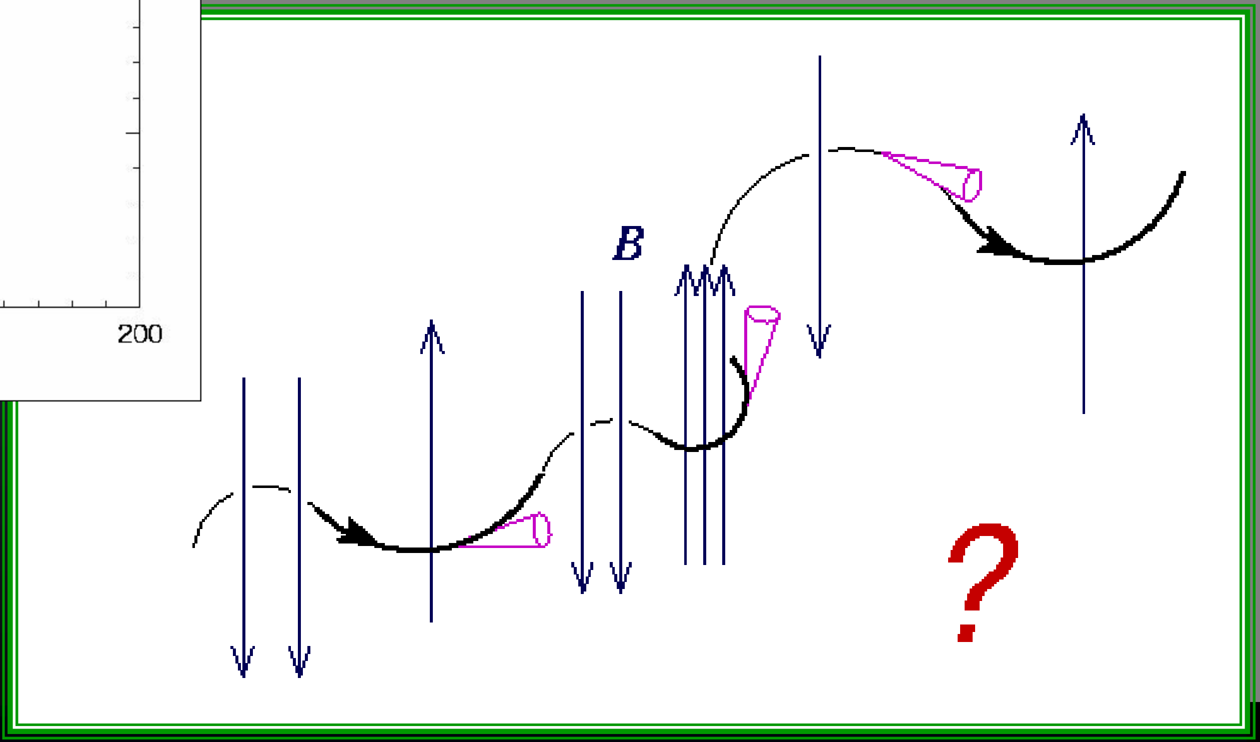
Synchrotron Vs. Jitter Radiation



$B(r)=B_1(r)$, $B_0=0$

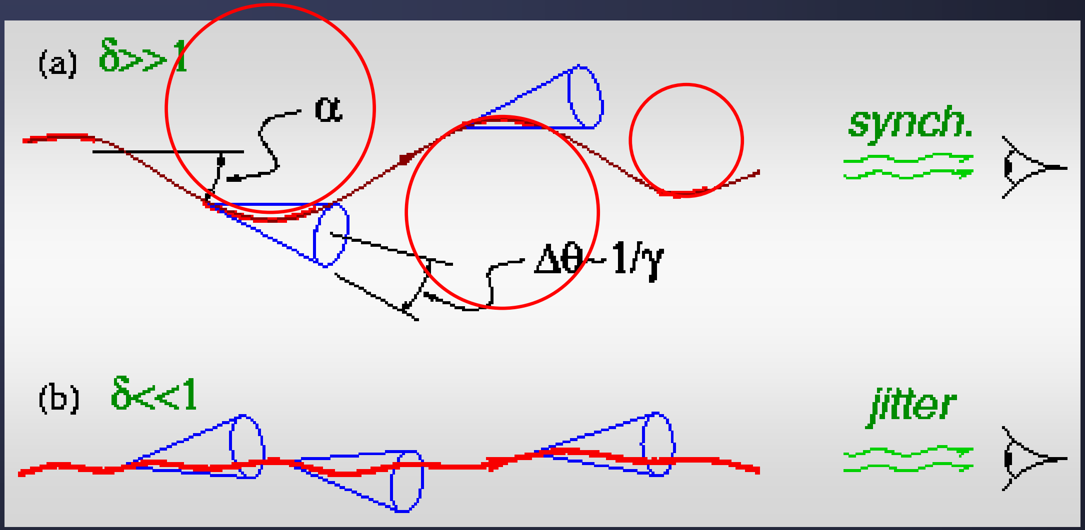
(highly inhomogeneous, random)

(Frederiksen, 2005, PhD thesis)



(Medvedev 2000, ApJ)

Regimes



$\omega_s \sim \gamma^2 \omega_H$

$\omega_j \sim \gamma^2 c/\lambda$

Deflection parameter:

$$\boxed{\delta = \frac{\alpha}{\Delta\theta} = \frac{eB\lambda}{mc^2}}$$

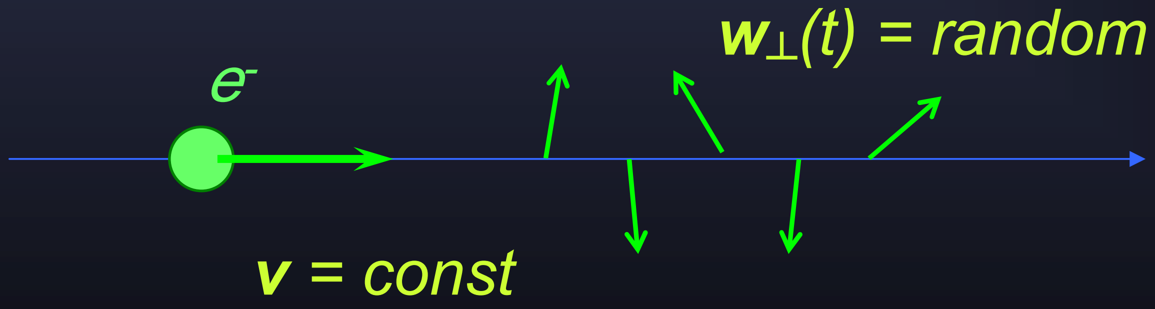
... independent of γ !

(Medvedev, 2000, ApJ)

Jitter regime

When $\delta << 1$, one can assume that

- particle is highly relativistic $\gamma >> 1$
- particle's trajectory is *piecewise-linear*
- particle velocity is nearly constant $r(t) = r_0 + \mathbf{c}\, t$
- particle experiences random acceleration $\mathbf{w}_\perp(t)$



Jitter radiation. Theory

Lienard-Wichert potentials

$$dW = \frac{e^2}{2\pi c^3}\left(\frac{\omega}{\omega'}\right)^4 \left|\boldsymbol{n}\times\left[\left(\boldsymbol{n}-\frac{\boldsymbol{v}}{c}\right)\times \boldsymbol{w}_{\omega'}\right]\right|^2 d\Omega\, \frac{d\omega}{2\pi}$$

where $\boldsymbol{w}_{\omega'} = \int \boldsymbol{w} e^{i\omega' t}\, dt$ is the Fourier component of the particle's acceleration, $\omega' = \omega(1 - \boldsymbol{n}\cdot\boldsymbol{v}/c)$, and $\boldsymbol{n}$ is the unit vector pointing toward the observer.

Small-angle approximation

The dominant contribution to the integral comes from small angles $\theta \sim 1/\gamma$

$$\begin{aligned} \omega' &\simeq \omega(1 - v/\,c + \theta^2/2) \\ &\simeq \omega/2(1 - v^2/c^2 + \theta^2) \\ &= \omega/2(\theta^2 + \gamma^{-2}) \end{aligned}$$

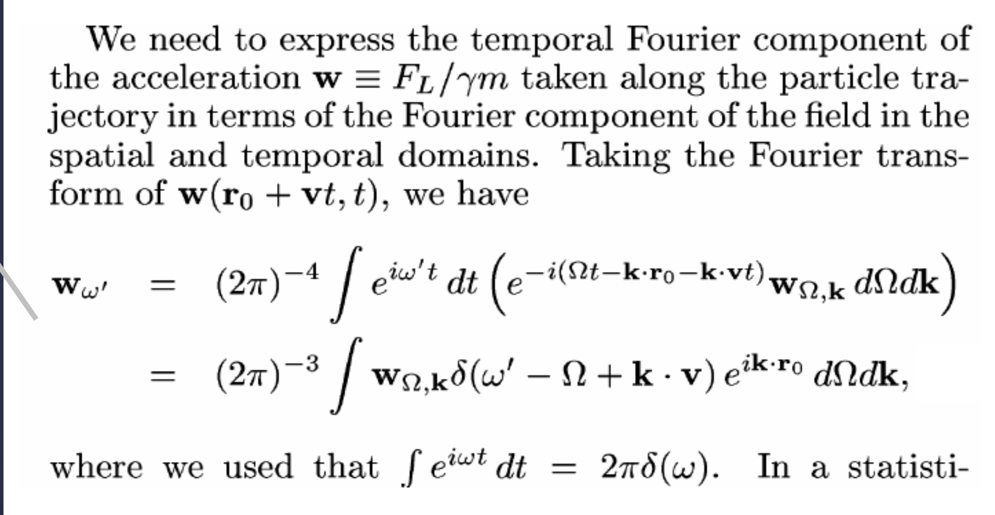
$$\frac{dW}{d\omega} = \frac{e^2\omega}{2\pi c^3}\int_{\omega/2\gamma^2}^{\infty} \frac{|\boldsymbol{w}_{\omega'}|^2}{\omega'^2}\left(1 - \frac{\omega}{\omega'\gamma^2} + \frac{\omega^2}{2\omega'^2\gamma^4}\right)d\omega'$$

Spectral power

(Landau & Lifshitz, 1963; Medvedev, ApJ, 2000)

Jitter radiation. Theory (cont.)

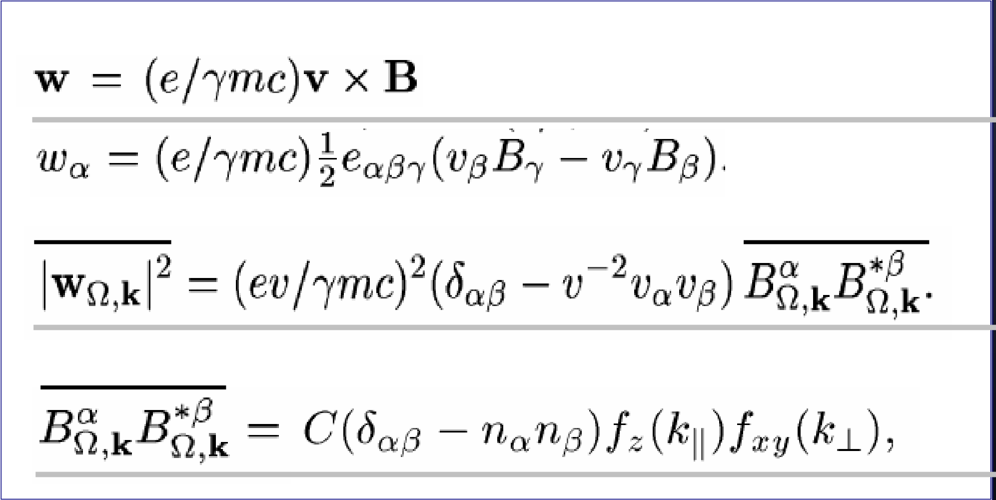
Fourier image of the particle acceleration from the 3D “(vxB) acceleration field”



We need to express the temporal Fourier component of the acceleration $\mathbf{w} \equiv F_L/\gamma m$ taken along the particle trajectory in terms of the Fourier component of the field in the spatial and temporal domains. Taking the Fourier transform of $\mathbf{w}(\mathbf{r}_0 + \mathbf{v}t, t)$, we have

$$\begin{aligned} \mathbf{w}_{\omega'} &= (2\pi)^{-4} \int e^{i\omega' t}\, dt \left(e^{-i(\Omega t - \mathbf{k}\cdot\mathbf{r}_0 - \mathbf{k}\cdot\mathbf{v}t)} \mathbf{w}_{\Omega,\mathbf{k}}\, d\Omega d\mathbf{k} \right) \\ &= (2\pi)^{-3} \int \mathbf{w}_{\Omega,\mathbf{k}} \delta(\omega' - \Omega + \mathbf{k}\cdot\mathbf{v})\, e^{i\mathbf{k}\cdot\mathbf{r}_0}\, d\Omega d\mathbf{k}, \end{aligned}$$

where we used that $\int e^{i\omega t}\, dt = 2\pi\delta(\omega)$. In a statisti-



$$\mathbf{w} = (e/\gamma mc)\mathbf{v} \times \mathbf{B}$$

$$w_\alpha = (e/\gamma mc)\tfrac{1}{2} e_{\alpha\beta\gamma}(v_\beta B_\gamma - v_\gamma B_\beta).$$

$$\overline{|\mathbf{w}_{\Omega,\mathbf{k}}|^2} = (ev/\gamma mc)^2(\delta_{\alpha\beta} - v^{-2} v_\alpha v_\beta)\, \overline{B^\alpha_{\Omega,\mathbf{k}} B^{*\beta}_{\Omega,\mathbf{k}}}.$$

$$\overline{B^\alpha_{\Omega,\mathbf{k}} B^{*\beta}_{\Omega,\mathbf{k}}} = C(\delta_{\alpha\beta} - n_\alpha n_\beta) f_z(k_\|) f_{xy}(k_\perp),$$

Lorentz force

Ensemble-averaged acceleration spectrum

B-field spectrum

(Landau & Lifshitz, 1963; Medvedev, ApJ, 2000; Fleishman, ApJ, 2006, Medvedev, ApJ, 2006)

Jitter radiation. 1D model

Characteristic frequency

$$\omega_j = \gamma^2 k_{Be} c = 2^{7/4} \gamma^2 \gamma_{\rm int} \bar{\gamma}_e^{-1/2} \omega_{\rm pe}$$

Power spectrum, F_ν

$$P(\omega) = r_e^2 c \gamma^2 \frac{\bar{B}_{\rm SS}^2}{2\omega_j} J\left(\frac{\omega}{\omega_j}\right)$$

where

$$J(\xi) = (2\mu + 1)\xi^{2\mu}\left[I\left(\min\left\{2, \frac{\xi}{\delta}\right\}\right) - I(\xi)\right]$$

where I is the integral,

$$I(\xi) = \int \xi^{-2\mu}(1 - \xi + \tfrac{1}{2}\xi^2) d\xi,$$

Total emitted power

$$dW/dt = (2/3) r_e^2 c \gamma^2 \bar{B}_{\rm SS}^2 .$$

← Exactly the same as
for synchrotron radiation

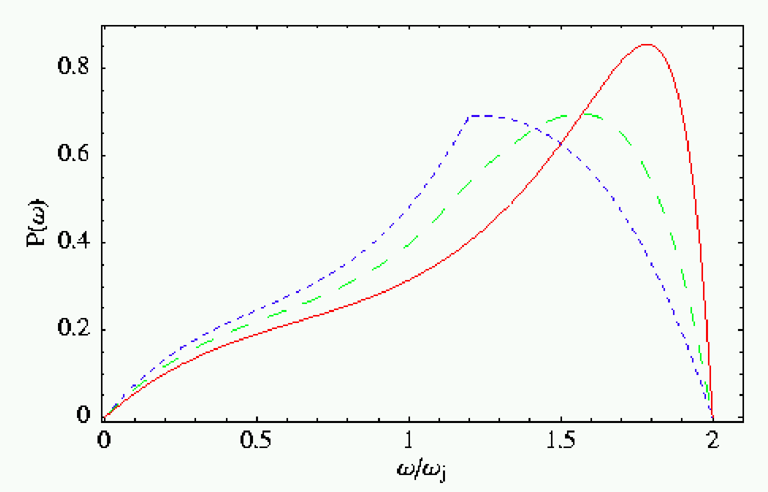
(Medvedev, ApJ, 2000)

Jitter Spectra: F_ν (1D)

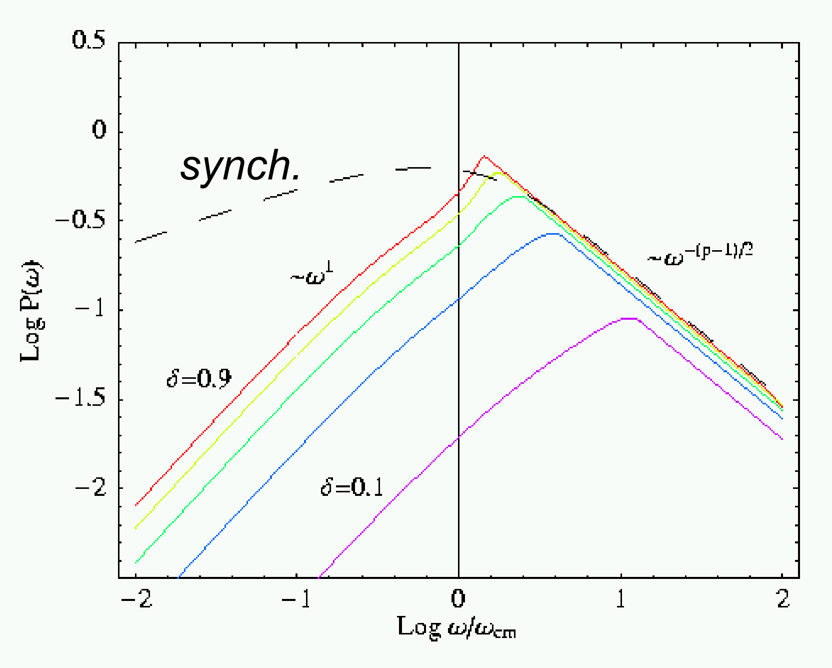
Weibel instability: $0 < k < k_{\max} \sim \omega_{p,e}/c$

Assume, for illustration: $\langle B_k^2 \rangle \sim k^{2\mu}$, , $\mu > 1$

Single electron



Power-law electrons

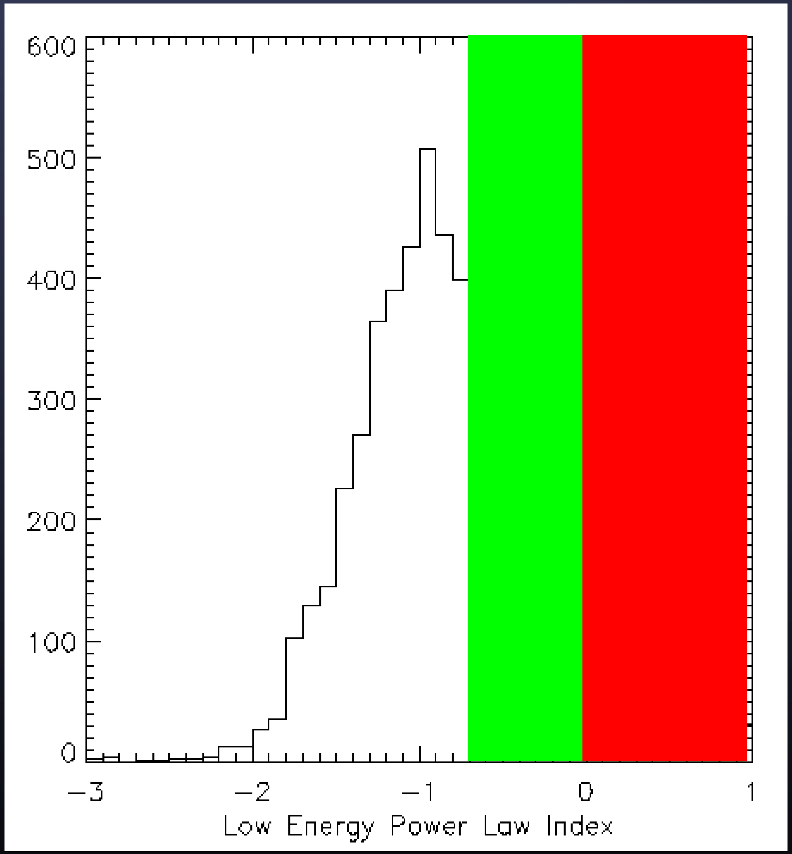


$N(\gamma) \sim \gamma^{-p}$, $\gamma > \gamma_{\min}$

(Medvedev, ApJ, 2000)

Synchrotron "Line of Death"

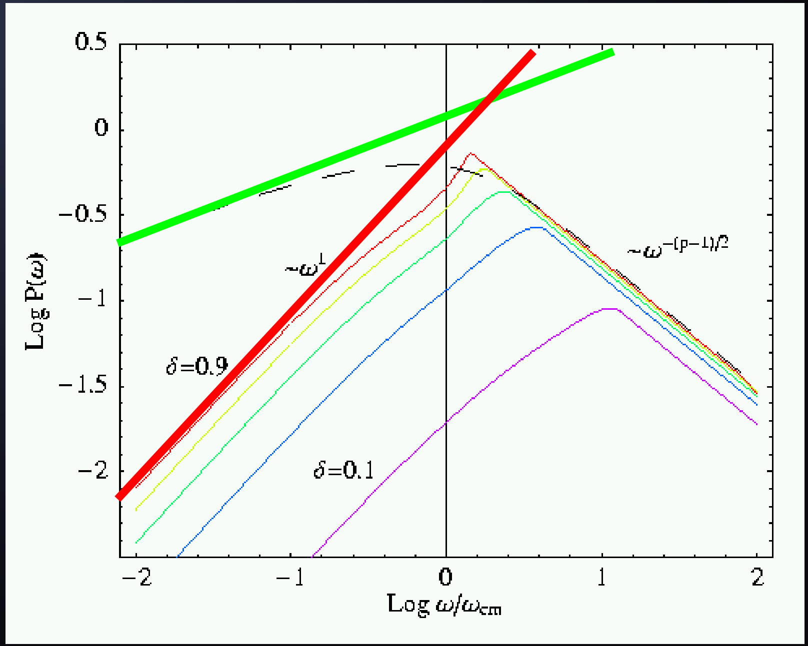
About 30% of BATSE GRBs and 50% of BSAX GRBs have photon soft indices α greater than –2/3, inconsistent with optically thin Synchrotron Shock Model



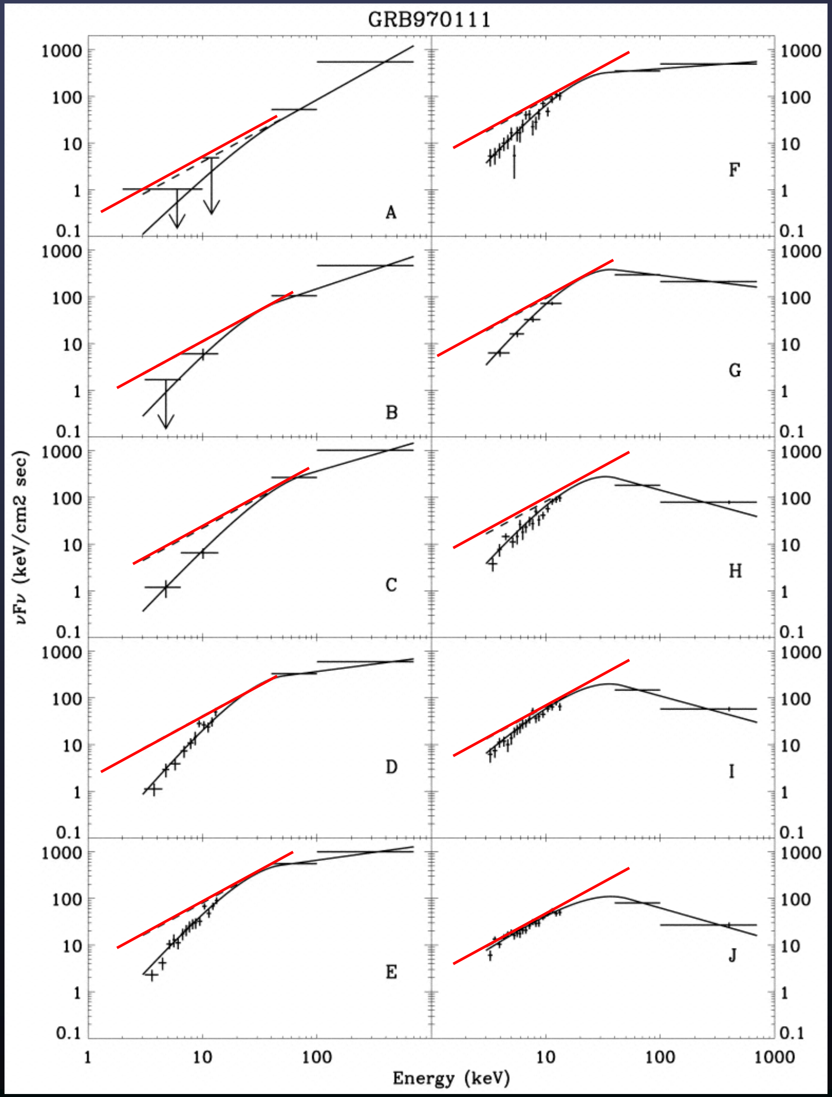
(Preece, et al., ApJS, 2000)

$$F_\nu \sim \nu^{\alpha+1}$$

(Medvedev, 2000)



Beppo-SAX spectra

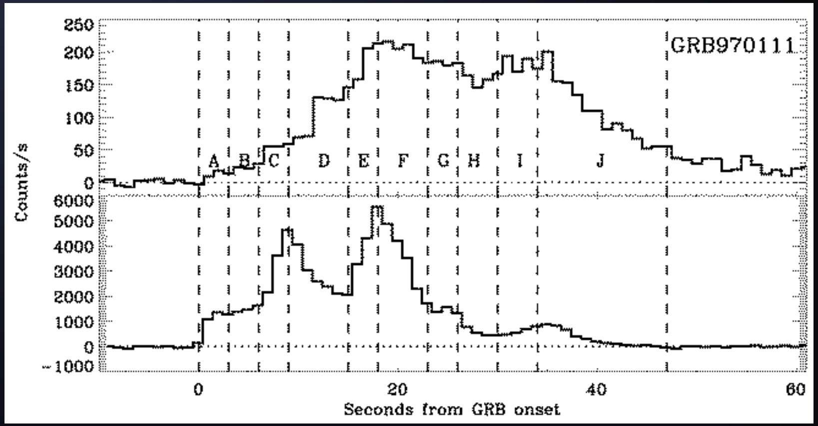


In a sample of 8 GRBs (2-700keV)
50% *violate* synchrotron limit

GRB 970111

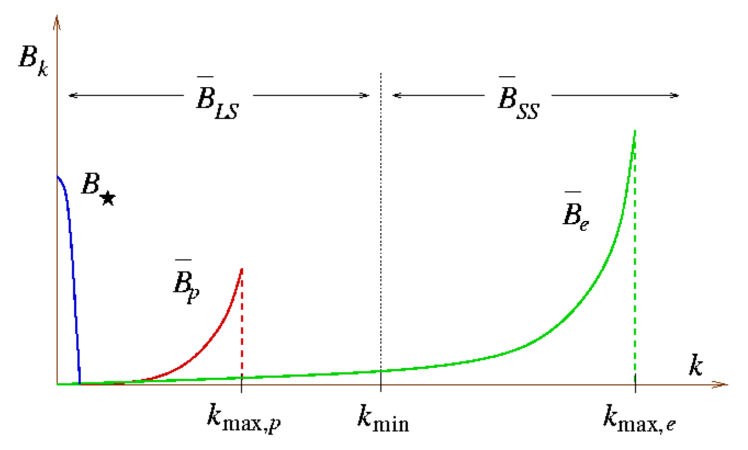
soft photon index *violates*

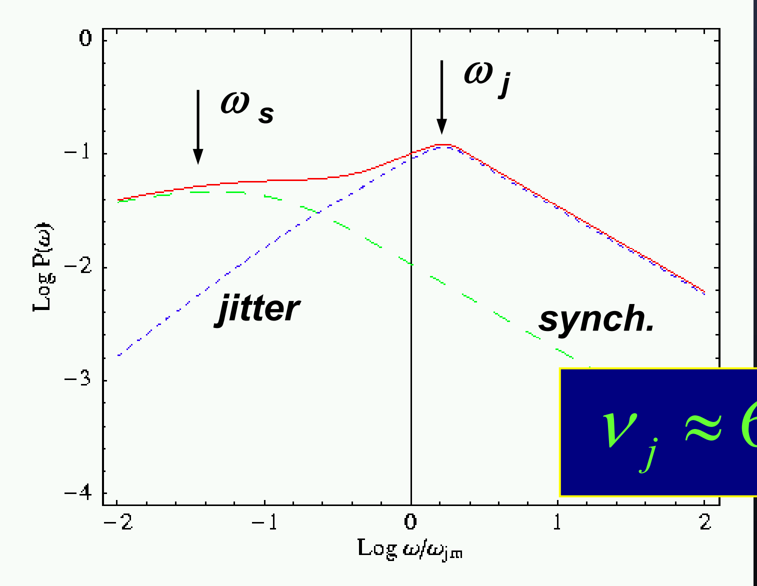
synchrotron limit for the entire burst



(Frontera, et al., ApJ, 2000)

Composite Model of Spectra





(Medvedev, ApJ, 2000)

Frequencies

$$\frac{\omega_s}{\omega_j} = \frac{3}{2}\frac{B_{LS}}{B_{SS}}\delta$$

Fluxes

$$\frac{F_{J,\max}}{F_{S,\max}} = f(p,\mu)\,\delta^2$$

$$\delta \approx \sqrt{(m_p/m_e)\varepsilon_B}$$

Break

$$\nu_j \approx 6\times10^9\ \gamma_{\min}^2\ \Gamma_{\rm sh}\ \Gamma_{\rm int}\ \bar{\gamma}_e^{-1/2}\ n_{e,10}^{1/2}\quad \text{Hz}$$

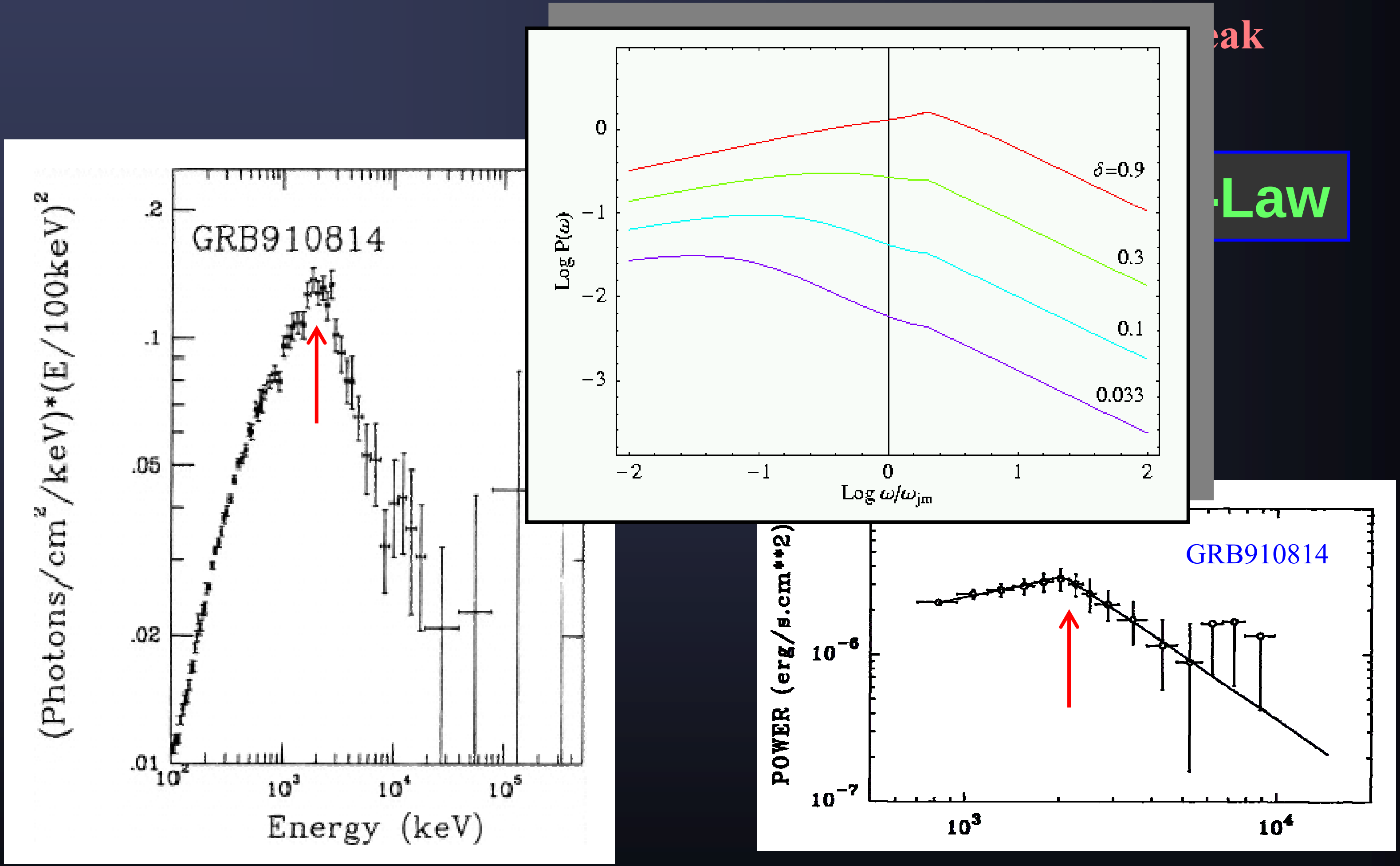
Sharply-broken bursts

Many bursts are:

- **better fit with a BPL spectral model**

eak

-Law



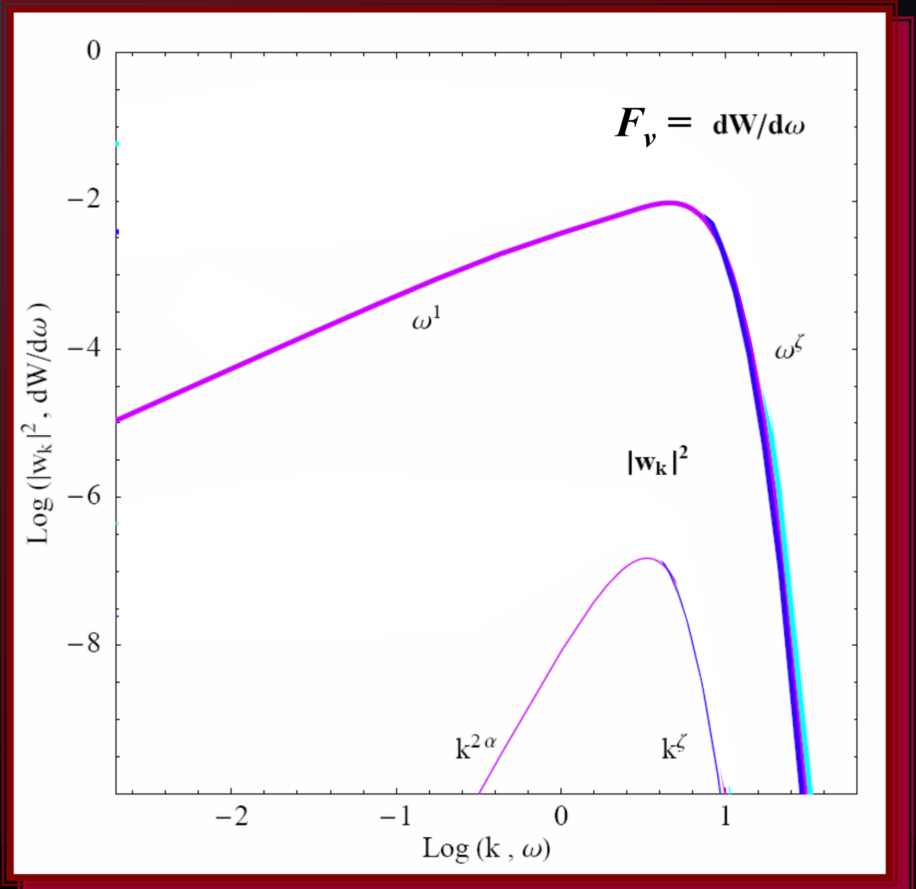
(CGRO: Schaefer, et al., ApJ, 1998)

(GRANAT: Pelaez, et al., ApJ, 1994)

Jitter does not work?

Fleishman, ApJ, in press, astro-ph/0502145

- ~~a low-frequency spectrum, $dI_\omega/d\omega \propto \omega^1$, valid in the presence of *ordered* small-scale magnetic field fluctuations, does not occur in the general case of small-scale *random* magnetic field fluctuations.~~



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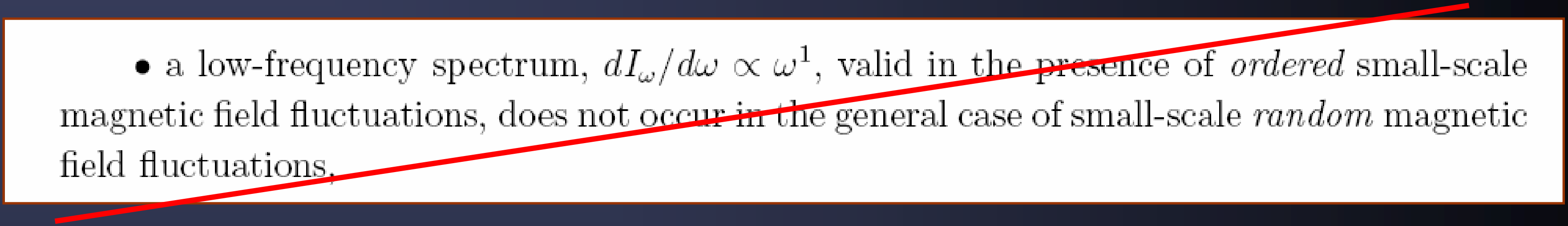

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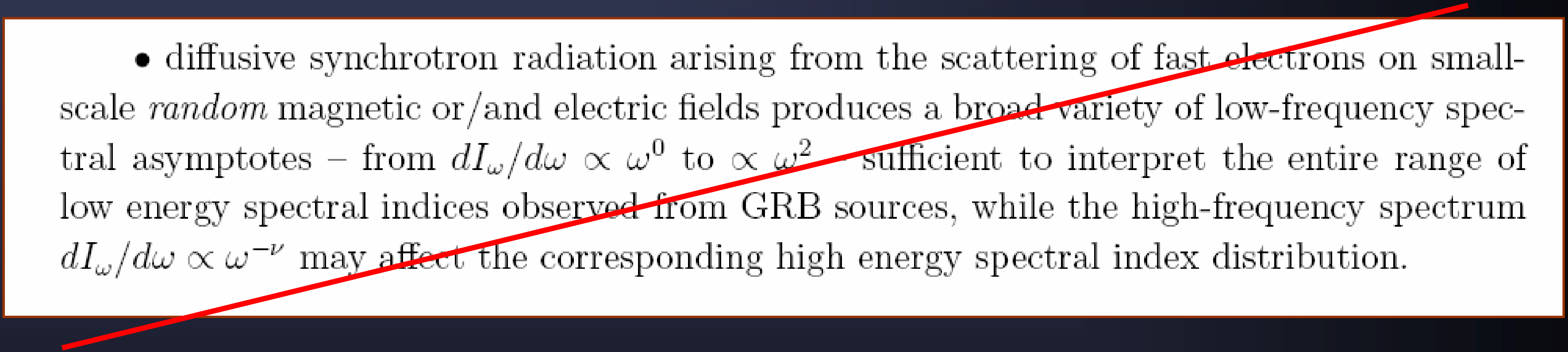

- ~~diffusive synchrotron radiation arising from the scattering of fast electrons on small-scale *random* magnetic or/and electric fields produces a broad variety of low-frequency spectral asymptotes – from $dI_\omega/d\omega \propto \omega^0$ to $\propto \omega^2$ – sufficient to interpret the entire range of low energy spectral indices observed from GRB sources, while the high-frequency spectrum $dI_\omega/d\omega \propto \omega^{-\nu}$ may affect the corresponding high energy spectral index distribution.~~

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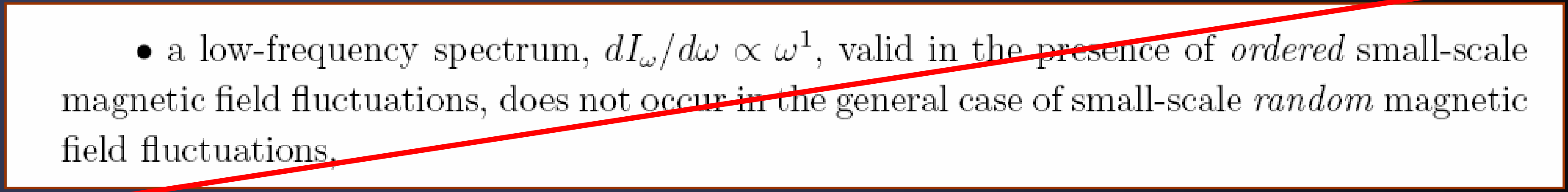

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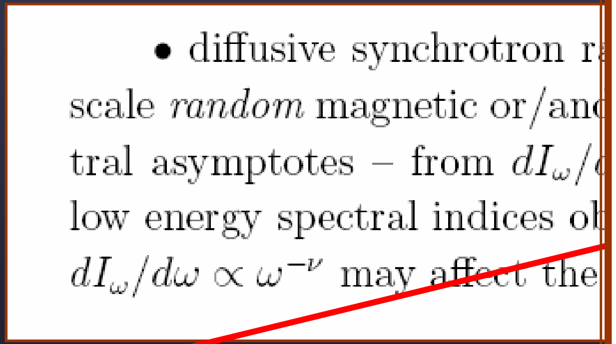

~~• diffusive synchrotron r~~
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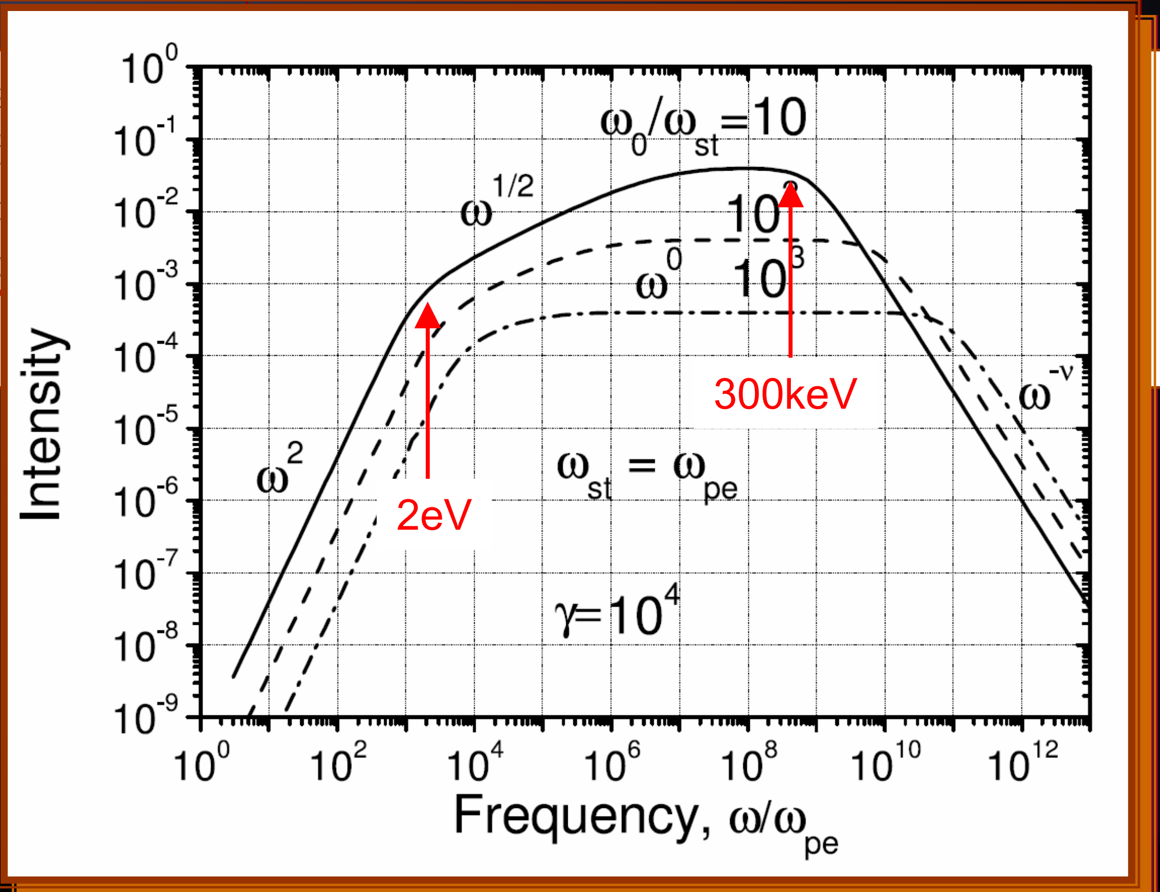

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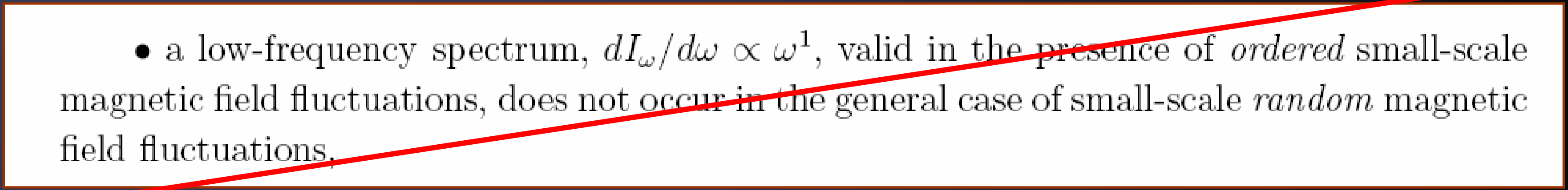

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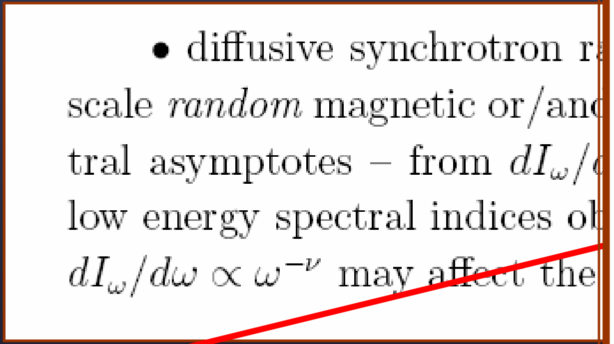

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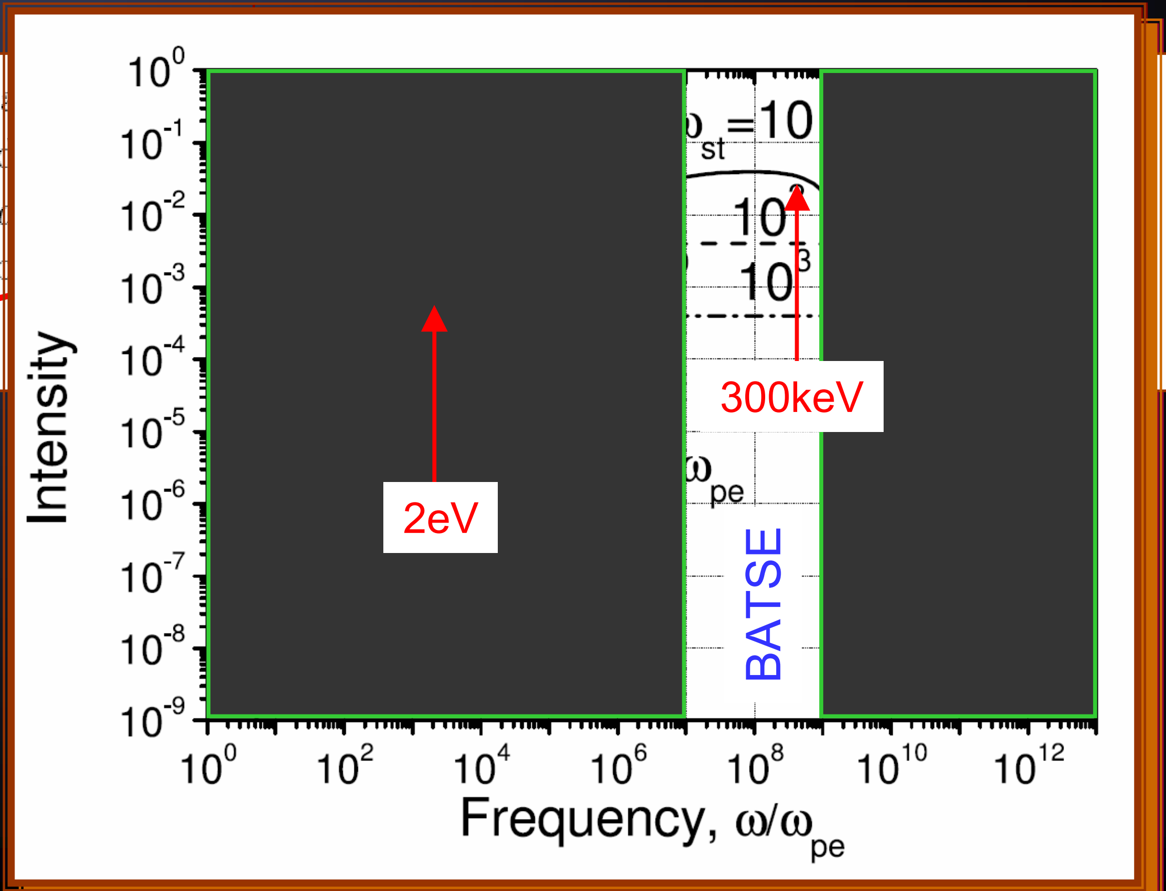

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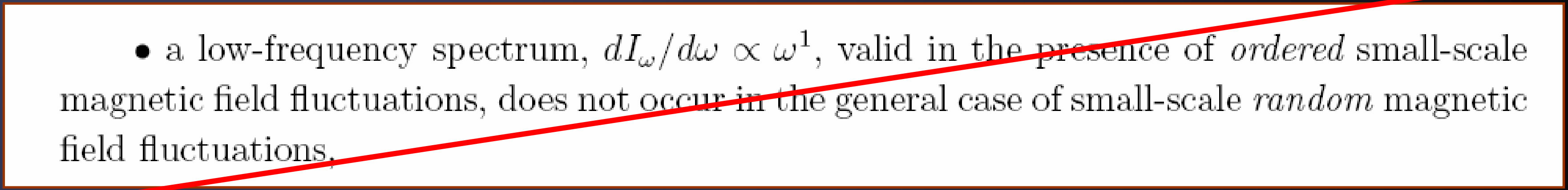

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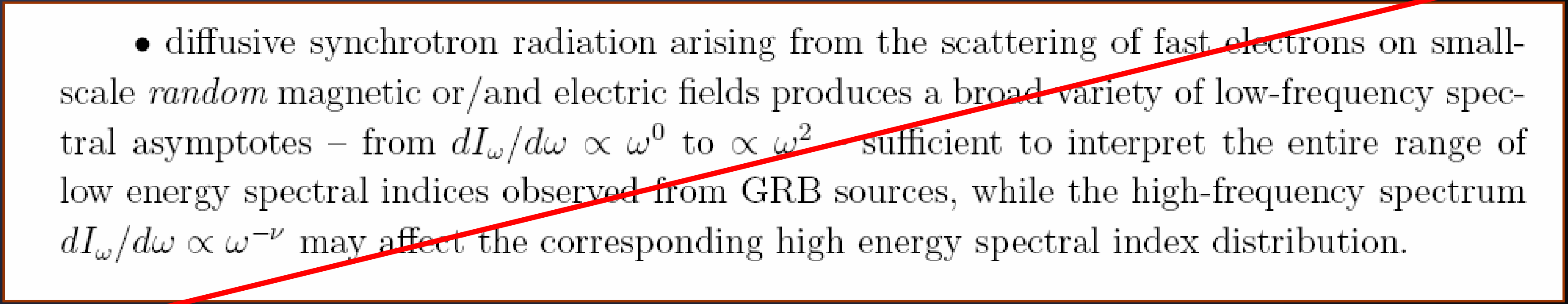

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All “diffusive synchrotron” calculations

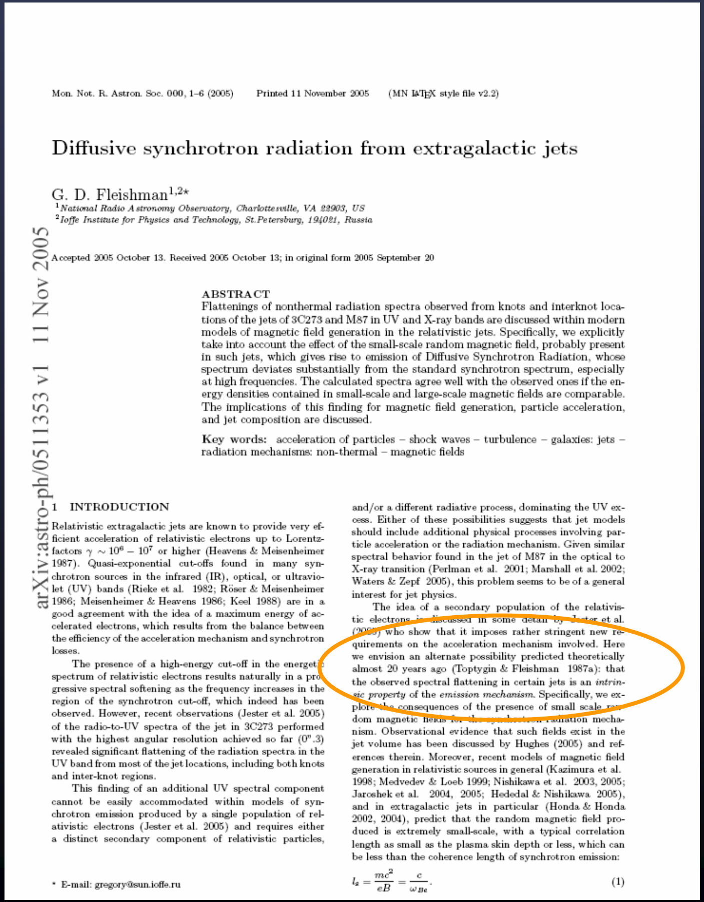
(perturbative and non-perturbative)

assume isotropic (!) field distribution.

→→ irrelevant for Weibel turbulence !!!

“Jitter” vs. “Diffusive Synchrotron”

No difference:
Same physical mechanism !



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Diffusive synchrotron radiation from extragalactic jets

G. D. Fleishman[1,2*]
[1] National Radio Astronomy Observatory, Charlottesville, VA 22903, US
[2] Ioffe Institute for Physics and Technology, St.Petersburg, 194021, Russia

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ABSTRACT
Flattenings of nonthermal radiation spectra observed from knots and interknot locations of the jets of 3C273 and M87 in UV and X-ray bands are discussed within modern models of magnetic field generation in the relativistic jets. Specifically, we explicitly take into account the effect of the small-scale random magnetic field, probably present in such jets, which gives rise to emission of Diffusive Synchrotron Radiation, whose spectrum deviates substantially from the standard synchrotron spectrum, especially at high frequencies. The calculated spectra agree well with the observed ones if the energy densities contained in small-scale and large-scale magnetic fields are comparable. The implications of this finding for magnetic field generation, particle acceleration, and jet composition are discussed.

Key words: acceleration of particles – shock waves – turbulence – galaxies: jets – radiation mechanisms: non-thermal – magnetic fields

1 INTRODUCTION

Relativistic extragalactic jets are known to provide very efficient acceleration of relativistic electrons up to Lorentz-factors $\gamma \sim 10^6 - 10^7$ or higher (Heavens & Meisenheimer 1987). Quasi-exponential cut-offs found in many synchrotron sources in the infrared (IR), optical, or ultraviolet (UV) bands (Rieke et al. 1982; Röser & Meisenheimer 1986; Meisenheimer & Heavens 1986; Keel 1988) are in a good agreement with the idea of a maximum energy of accelerated electrons, which results from the balance between the efficiency of the acceleration mechanism and synchrotron losses.

The presence of a high-energy cut-off in the energetic spectrum of relativistic electrons results naturally in a progressive spectral softening as the frequency increases in the region of the synchrotron cut-off, which indeed has been observed. However, recent observations (Jester et al. 2005) of the radio-to-UV spectra of the jet in 3C273 performed with the highest angular resolution achieved so far (0".3) revealed significant flattening of the radiation spectra in the UV band from most of the jet locations, including both knots and inter-knot regions.

This finding of an additional UV spectral component cannot be easily accommodated within models of synchrotron emission produced by a single population of relativistic electrons (Jester et al. 2005) and requires either a distinct secondary component of relativistic particles, and/or a different radiative process, dominating the UV excess. Either of these possibilities suggests that jet models should include additional physical processes involving particle acceleration or the radiation mechanism. Given similar spectral behavior found in the jet of M87 in the optical to X-ray transition (Perlman et al. 2001; Marshall et al. 2002; Waters & Zepf 2005), this problem seems to be of a general interest for jet physics.

The idea of a secondary population of the relativistic electrons is discussed in some detail by Jester et al. (2005) who show that it imposes rather stringent new requirements on the acceleration mechanism involved. Here we envision an alternate possibility predicted theoretically almost 20 years ago (Toptygin & Fleishman 1987a): that the observed spectral flattening in certain jets is an *intrinsic property* of the *emission mechanism*. Specifically, we explore the consequences of the presence of small scale random magnetic fields for the synchrotron radiation mechanism. Observational evidence that such fields exist in the jet volume has been discussed by Hughes (2005) and references therein. Moreover, recent models of magnetic field generation in relativistic sources in general (Kazimura et al. 1998; Medvedev & Loeb 1999; Nishikawa et al. 2003, 2005; Jaroshek et al. 2004, 2005; Hededal & Nishikawa 2005), and in extragalactic jets in particular (Honda & Honda 2002, 2004), predict that the random magnetic field produced is extremely small-scale, with a typical correlation length as small as the plasma skin depth or less, which can be less than the coherence length of synchrotron emission:

$$l_s = \frac{mc^2}{eB} = \frac{c}{\omega_{Be}}. \quad (1)$$

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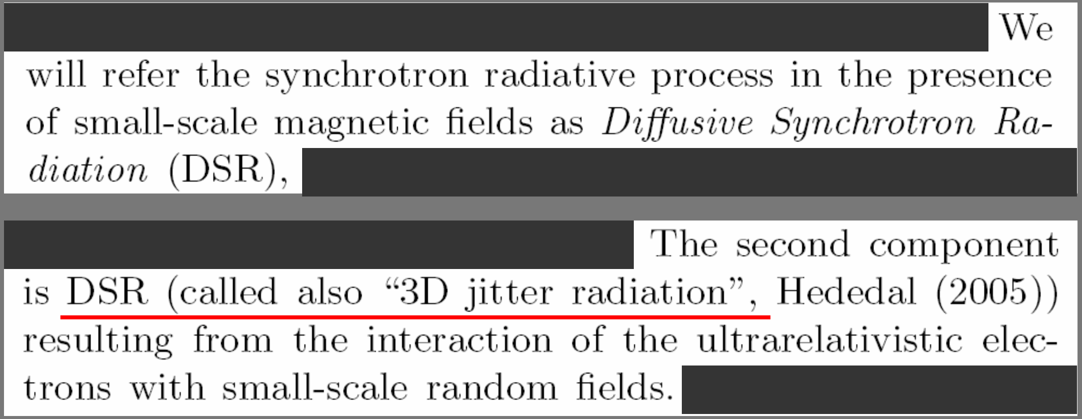
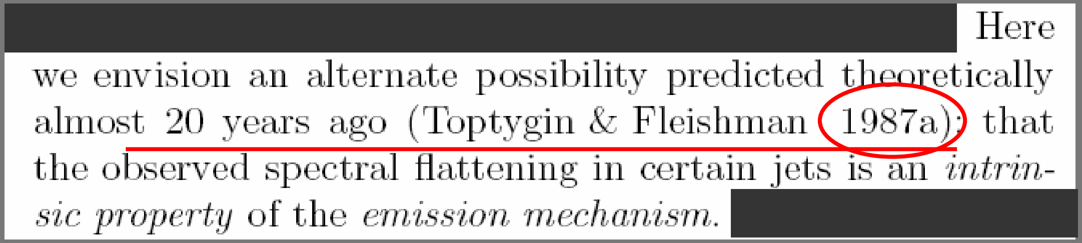
[*] E-mail: gregory@sun.ioffe.ru



[redacted] We will refer the synchrotron radiative process in the presence of small-scale magnetic fields as *Diffusive Synchrotron Radiation* (DSR), [redacted]

[redacted] The second component is DSR (called also “3D jitter radiation”, Hededal (2005)) resulting from the interaction of the ultrarelativistic electrons with small-scale random fields. [redacted]

(Fleishman, 2005, MNRAS (in press), astro-ph/0511353)



[redacted] Here we envision an alternate possibility predicted theoretically almost 20 years ago (Toptygin & Fleishman 1987a): that the observed spectral flattening in certain jets is an *intrinsic property* of the *emission mechanism*. [redacted]

Non-synchrotron in B- & E-fields

➢ Landau-Migdal-Pomeranchuk effect	Landau & Pomeranchuk, *Dokl. Akad. Nauk SSSR* **92**, 535 (1953) Migdal, *Phys. Rev.* **103**, 1811 (1956)
➢ Undulator radiation	Nikitin & Medvedev, *Sov. Phys. Tech. Phys.* 20, 600 (1975)
➢ Free-electron laser	Kwan, Dawson, & Lin, *Phys. Fluids* 20, 581 (1977)
➢ Wiggler radiation	Kincaid, *J. Appl. Phys.* 48, 2684 (1977)
➢ Transition radiation	
➢ textbooks	Landau & Lifshitz, Field Theory (1963) Ginzburg & Syrovatskii (1964)
➢ radiation from various types of turbulence	Tsytovich, & Chikhachev, *Sov. Astron.,* 13, 385 (1969) Getmantsev, & Tokarev, *Astrophys. Lett*, 12, 57 (1972) Getmantsev, & Tokarev, *Ap&SS,* 18, 135 (1972) Nikolaev, & Tsytovich, *Phys. Scripta*, 20, 665 (1979)

Non-synchrotron in B- & E-fields

- Landau-Mi

d. Nauk SSSR **92**, 535 (1953)

Pomeranchuk

6)

- textbooks

- radiation fr

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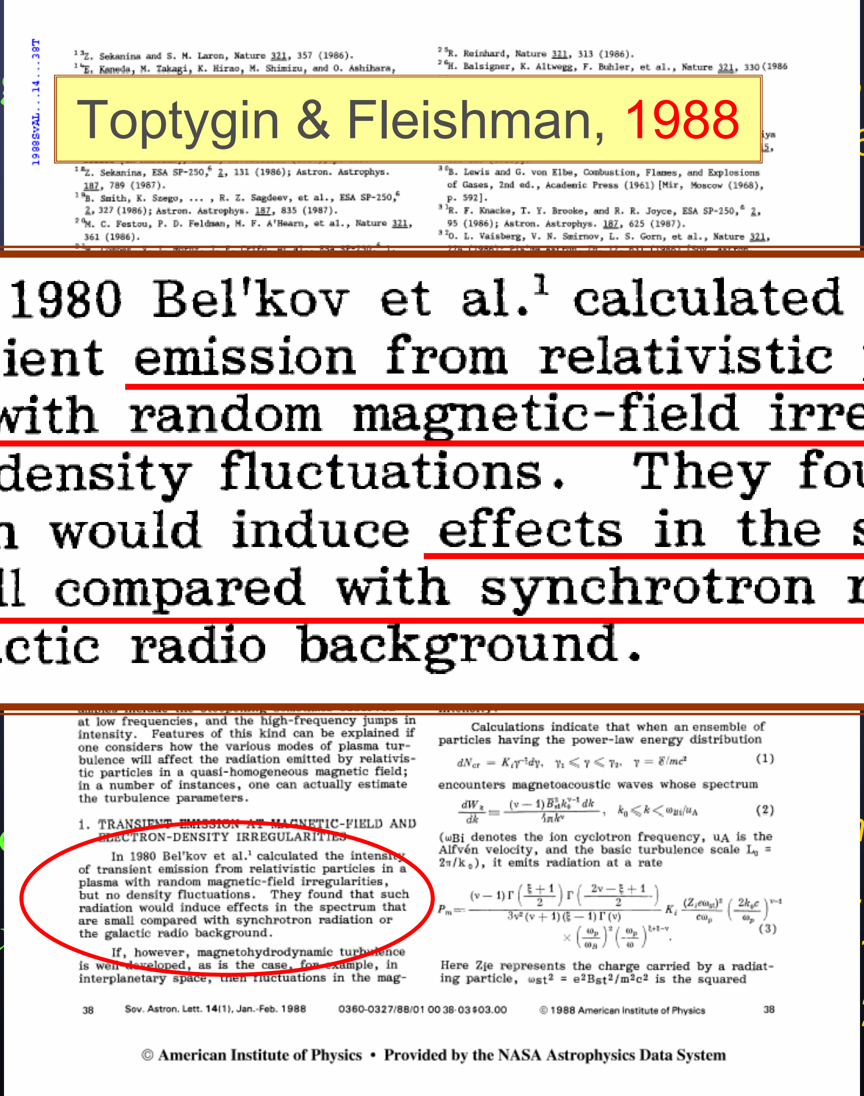

Toptygin & Fleishman, 1988

In 1980 Bel'kov et al.[1] calculated the intensity of transient emission from relativistic particles in a plasma with random magnetic-field irregularities, but no density fluctuations. They found that such radiation would induce effects in the spectrum that are small compared with synchrotron radiation or the galactic radio background.

1988SvAL...14...38T

[13] Z. Sekanina and S. M. Laron, Nature 321, 357 (1986).

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[18] Z. Sekanina, ESA SP-250,[6] 2, 131 (1986); Astron. Astrophys. 187, 789 (1987).

[19] B. Smith, K. Szego, ... , R. Z. Sagdeev, et al., ESA SP-250,[6] 2, 327 (1986); Astron. Astrophys. 187, 835 (1987).

[20] M. C. Festou, P. D. Feldman, M. F. A'Hearn, et al., Nature 321, 361 (1986).

[25] R. Reinhard, Nature 321, 313 (1986).

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[30] B. Lewis and G. von Elbe, Combustion, Flames, and Explosions of Gases, 2nd ed., Academic Press (1961) [Mir, Moscow (1968), p. 592].

[31] R. F. Knacke, T. Y. Brooke, and R. R. Joyce, ESA SP-250,[6] 2, 95 (1986); Astron. Astrophys. 187, 625 (1987).

[32] O. L. Vaisberg, V. N. Smirnov, L. S. Gorn, et al., Nature 321,

at low frequencies, and the high-frequency jumps in intensity. Features of this kind can be explained if one considers how the various modes of plasma turbulence will affect the radiation emitted by relativistic particles in a quasi-homogeneous magnetic field; in a number of instances, one can actually estimate the turbulence parameters.

1. TRANSIENT EMISSION AT MAGNETIC-FIELD AND ELECTRON-DENSITY IRREGULARITIES

In 1980 Bel'kov et al.[1] calculated the intensity of transient emission from relativistic particles in a plasma with random magnetic-field irregularities, but no density fluctuations. They found that such radiation would induce effects in the spectrum that are small compared with synchrotron radiation or the galactic radio background.

If, however, magnetohydrodynamic turbulence is well developed, as is the case, for example, in interplanetary space, then fluctuations in the mag-

Calculations indicate that when an ensemble of particles having the power-law energy distribution

$$dN_{cr} = K_\xi \gamma^{-\xi} d\gamma, \quad \gamma_1 \leqslant \gamma \leqslant \gamma_2, \quad \gamma = \mathscr{E}/mc^2 \tag{1}$$

encounters magnetoacoustic waves whose spectrum

$$\frac{dW_k}{dk} = \frac{(\nu-1) B_{st}^2 k_0^{\nu-1}\, dk}{4\pi k^\nu}, \quad k_0 \leqslant k < \omega_{Bi}/u_A \tag{2}$$

(ω_{Bi} denotes the ion cyclotron frequency, u_A is the Alfvén velocity, and the basic turbulence scale $L_0 = 2\pi/k_0$), it emits radiation at a rate

$$P_m = \frac{(\nu-1)\Gamma\left(\frac{\xi+1}{2}\right)\Gamma\left(\frac{2\nu-\xi+1}{2}\right)}{3\nu^2(\nu+1)(\xi-1)\Gamma(\nu)} K_\xi \frac{(Z_i e \omega_{st})^2}{c\omega_p}\left(\frac{2k_0 c}{\omega_p}\right)^{\nu-1} \times \left(\frac{\omega_p}{\omega_B}\right)^2 \left(\frac{\omega_p}{\omega}\right)^{\xi+1-\nu}. \tag{3}$$

Here $Z_i e$ represents the charge carried by a radiating particle, $\omega_{st}^2 = e^2 B_{st}^2/m^2c^2$ is the squared

38 Sov. Astron. Lett. 14(1), Jan.-Feb. 1988 0360-0327/88/01 00 38-03$03.00 © 1988 American Institute of Physics 38

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Outline

Viewing angle effect

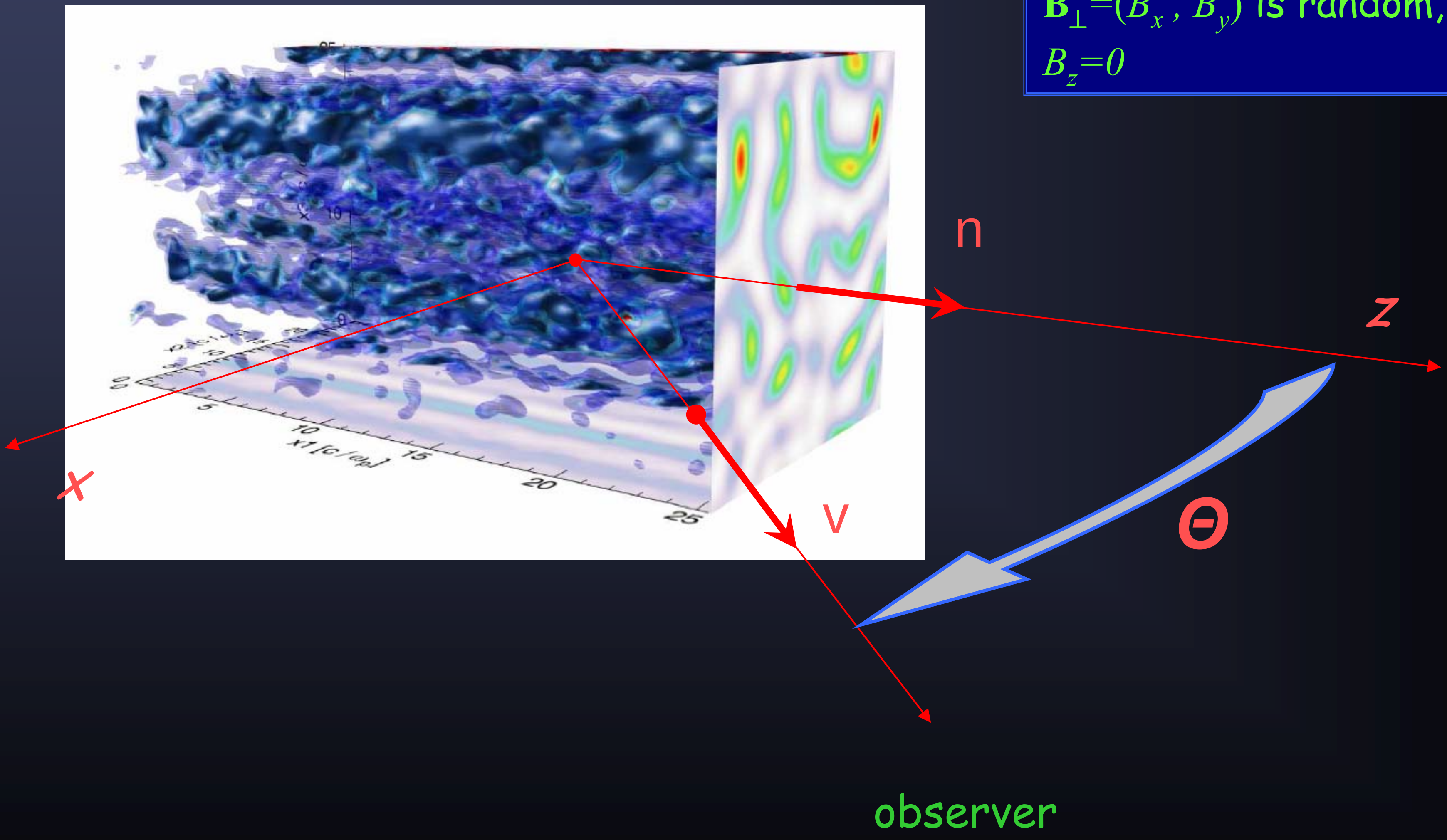
- Introduction:
  Shock microphysics, Weibel turbulence, particle acceleration
- Radiation production at shocks
- Spectral variability
- Shock emission in jets
- Polarization of radiation
- Summary

Radiation vs Θ

B-field is anisotropic:

$\mathbf{B}_\perp=(B_x\,, B_y)$ is random,

$B_z=0$



(Medvedev, Silva, Kamionkowski 2006; Medvedev 2006)

Jitter + Weibel theory -- summary

Spectral power of radiation

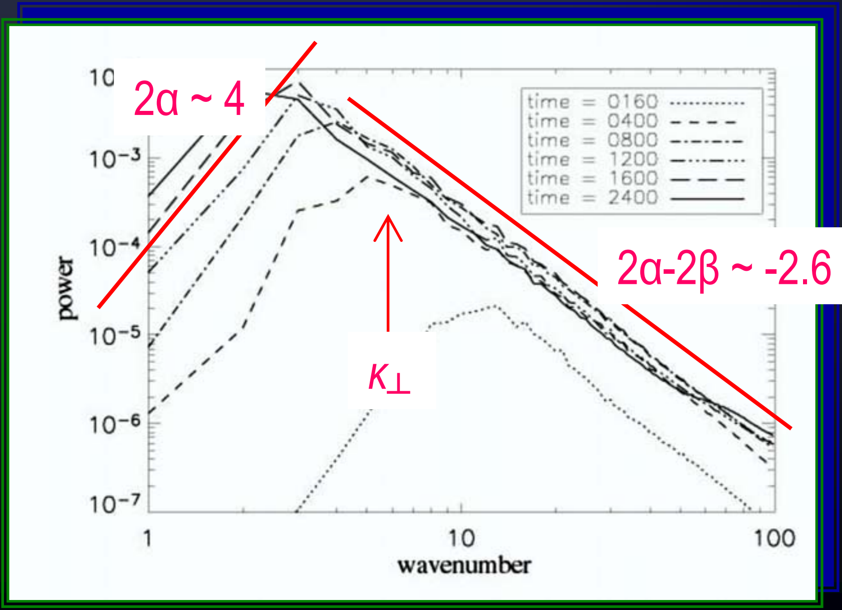
$$\frac{dW}{d\omega} = \frac{e^2\omega}{2\pi c^3}\int_{\omega/2\gamma^2}^{\infty}\frac{|\mathbf{w}_{\omega'}|^2}{\omega'^2}\left(1-\frac{\omega}{\omega'\gamma^2}+\frac{\omega^2}{2\omega'^2\gamma^4}\right)d\omega',$$

Electron's acceleration spectrum

$$\langle|\mathbf{w}_{\omega'}|^2\rangle = \frac{C}{2\pi}(1+\cos^2\Theta)\int f_z(k_\parallel)f_{xy}(k_\perp)\delta(\omega'+\mathbf{k}\cdot\mathbf{v})\,dk_\parallel\, d^2k_\perp.$$

Models of field spectra, independent in *z* and *xy* (!)

$$f_z(k_\parallel) = \frac{k_\parallel^{2\alpha_1}}{(\kappa_\parallel^2+k_\parallel^2)^{\beta_1}},\qquad f_{xy}(k_\perp) = \frac{k_\perp^{2\alpha_2}}{(\kappa_\perp^2+k_\perp^2)^{\beta_2}},$$



α_2 ~ 2

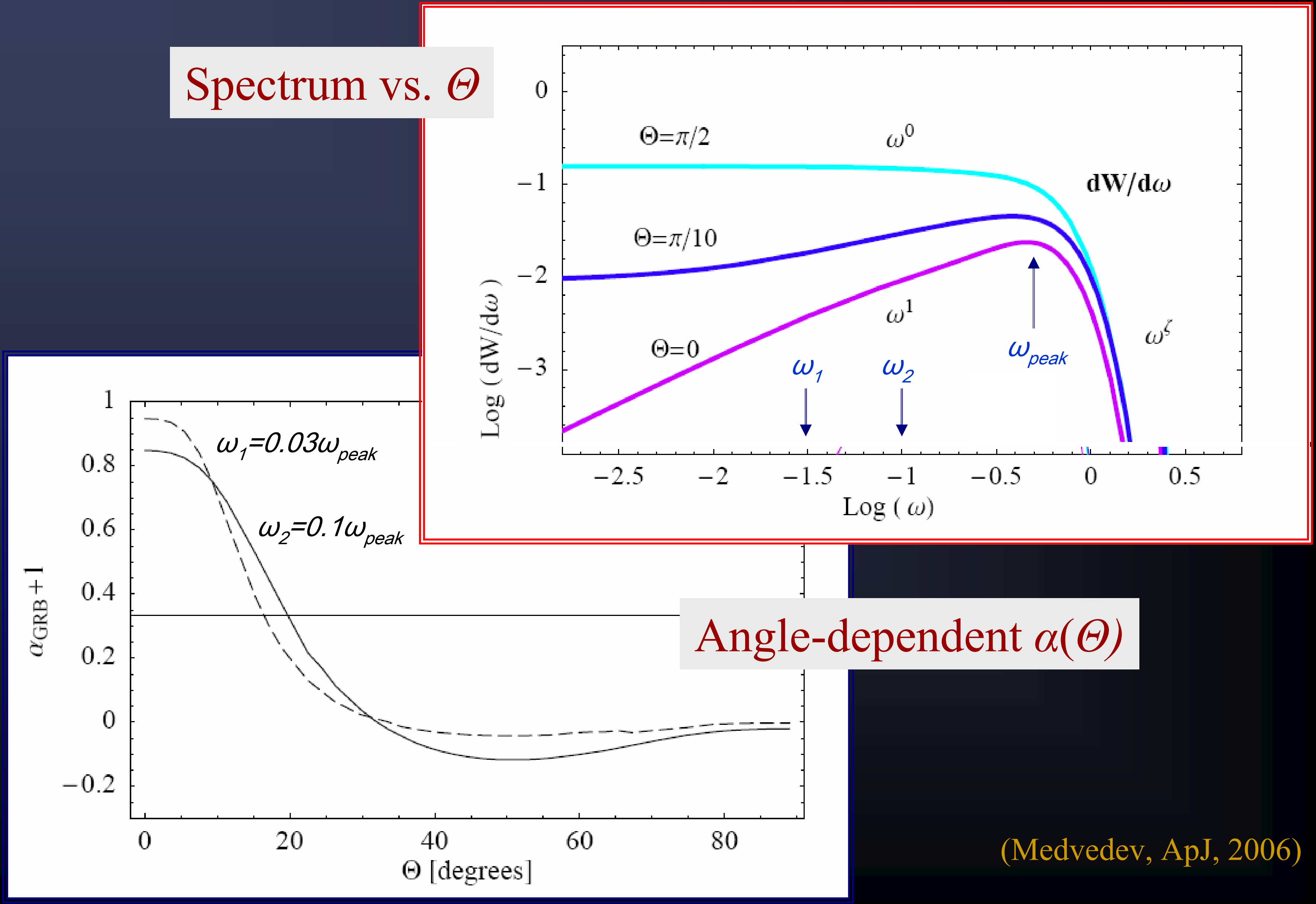
β_2 ~ -3.3

$\kappa_\perp$ ~ const. ($\omega_{p,e}/c$)

(Frederiksen, ApJL, 2004)

Spectrum vs. viewing angle

Spectrum vs. *Θ*

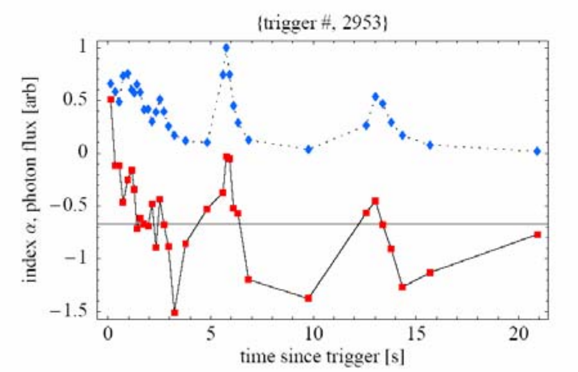


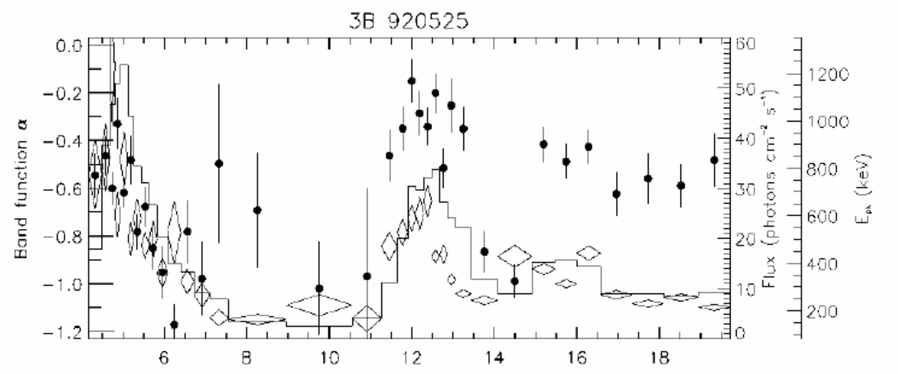
Angle-dependent *α*(*Θ*)

(Medvedev, ApJ, 2006)

"Tracking" GRBs

Also, "hardness – intensity" correlation ; *Also, "tracking behavior"*

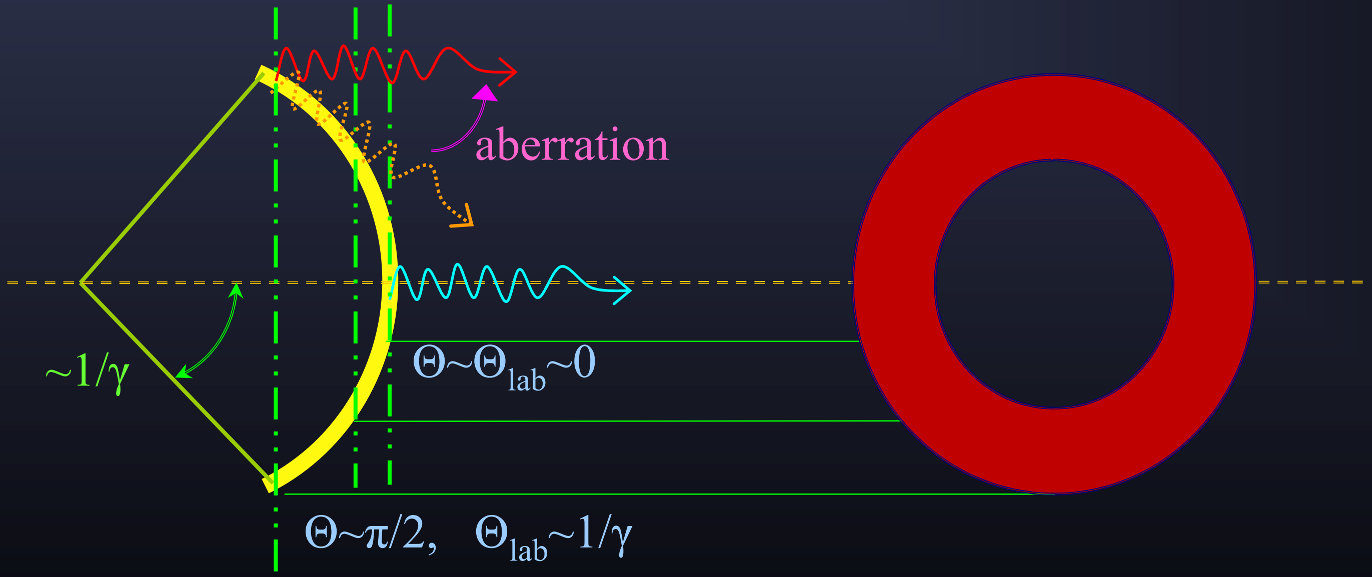




● = α

◊ = E_{peak}

— = Flux



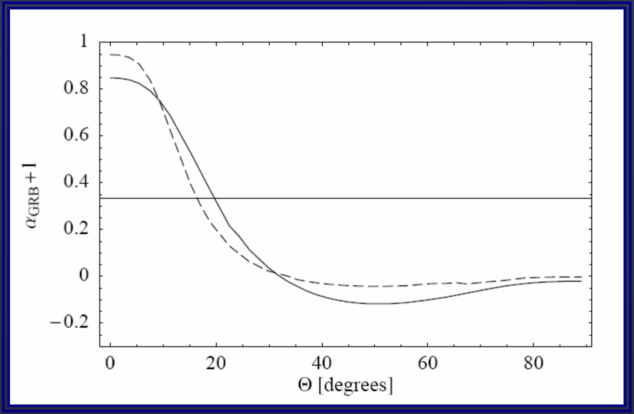
t_1, bright,
high E_{peak},
$\alpha \sim 0$

t_2, intermediate
$\alpha \sim -2/3$

t_3, faint,
low E_{peak},
$\alpha \sim -1$

Flux – *α* correlation

Also, “hardness – intensity” correlation ;   Also, “tracking behavior”



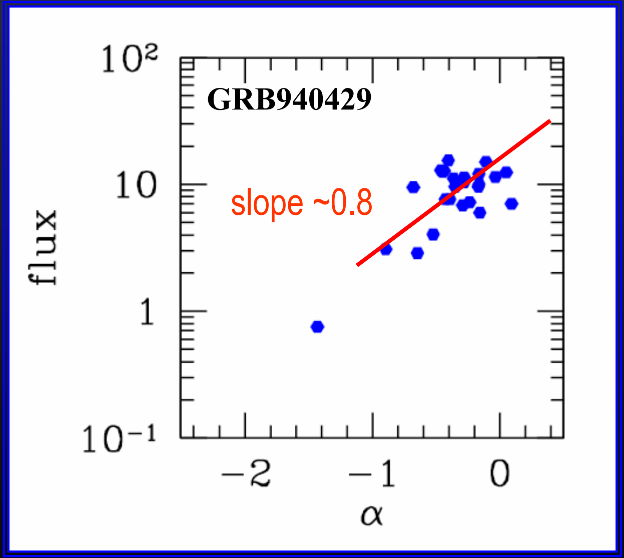
index *α* depends on *Θ*

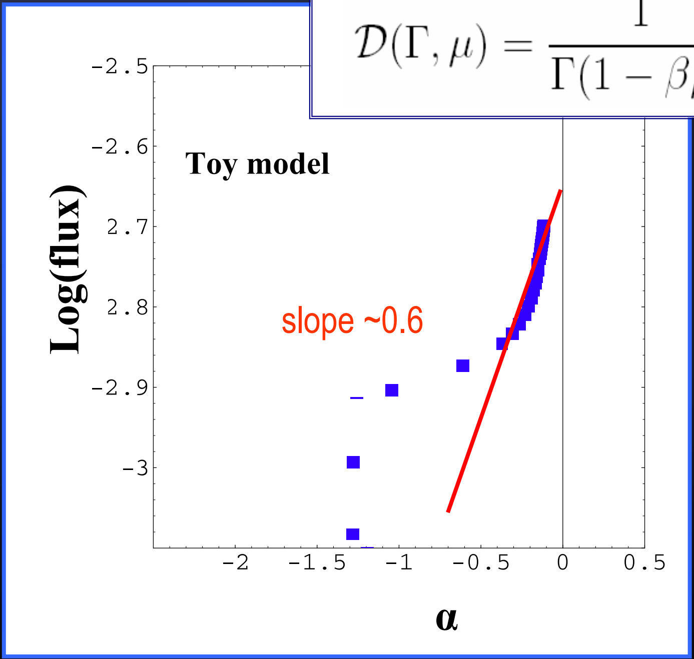
bolometric flux depends on *Θ*

$$F_{\text{bol}}(t) = F_0\mu\mathcal{D}^2(\mu)/\Gamma^2,$$

where the Lorentz boost is Θ-dependent

$$\mathcal{D}(\Gamma,\mu) = \frac{1}{\Gamma(1-\beta\mu)} \qquad \mu = \cos\theta$$

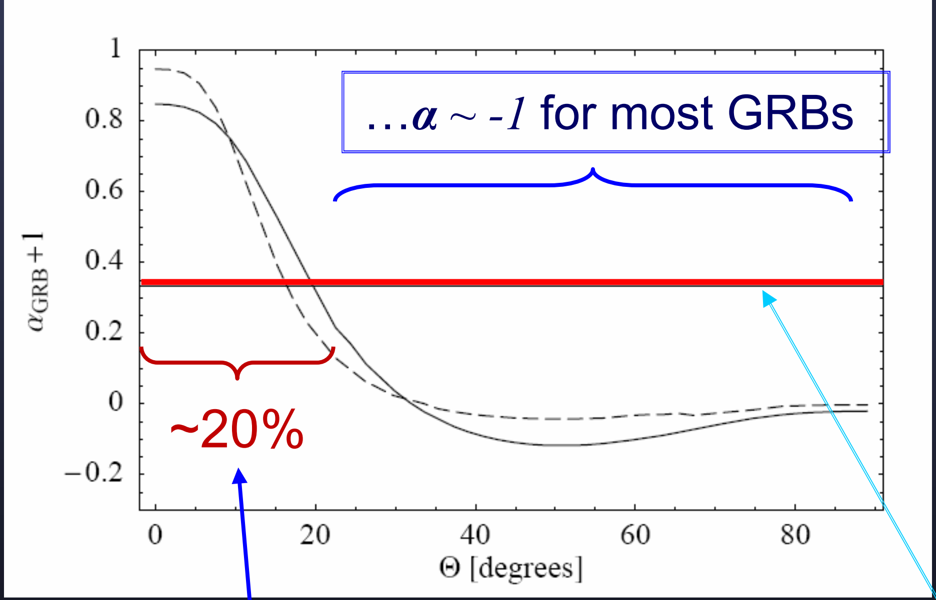




(Medvedev, ApJ, 2006)

Statistics of α

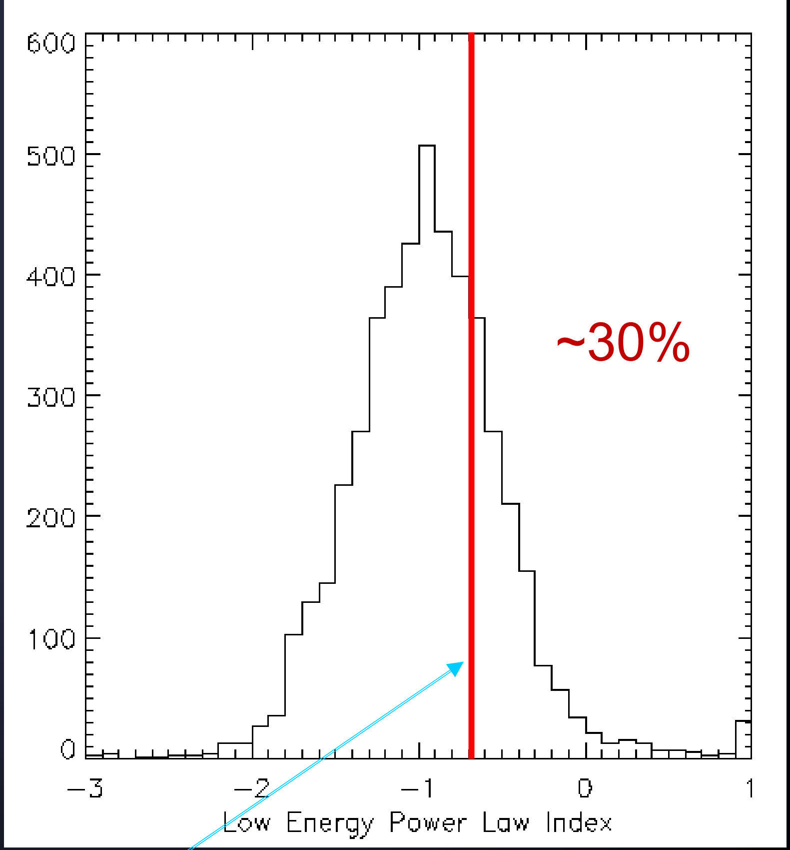
index α depends on Θ



…$\alpha \sim -1$ for most GRBs

~20%

…of GRB spectra violate SLoD



~30%

Synchrotron “Line of Death”

(Medvedev, ApJ, 2006)

(Preece, et al. 2000, ApJS)

Outline

Jitter from AGN jets?

- Introduction:
  Shock microphysics, Weibel tu ence, particle acceleration
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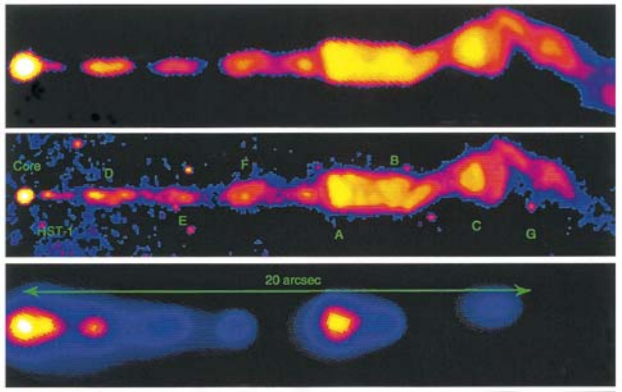
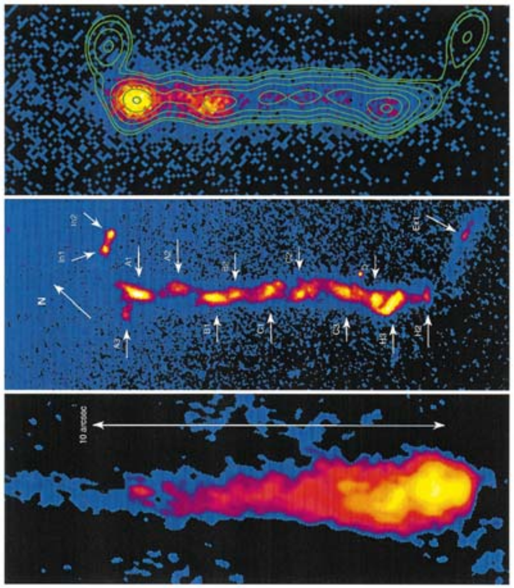
GRB-AGN jet connection



3C 273

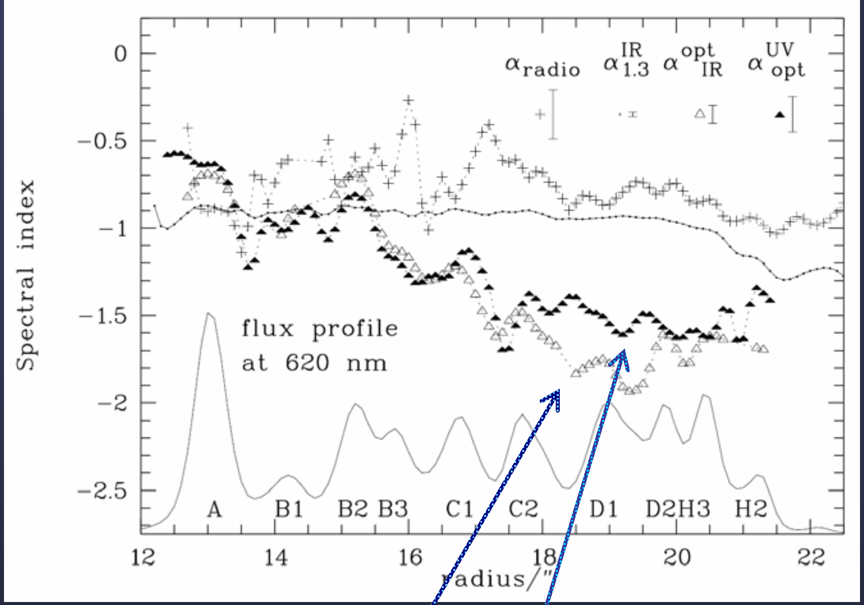


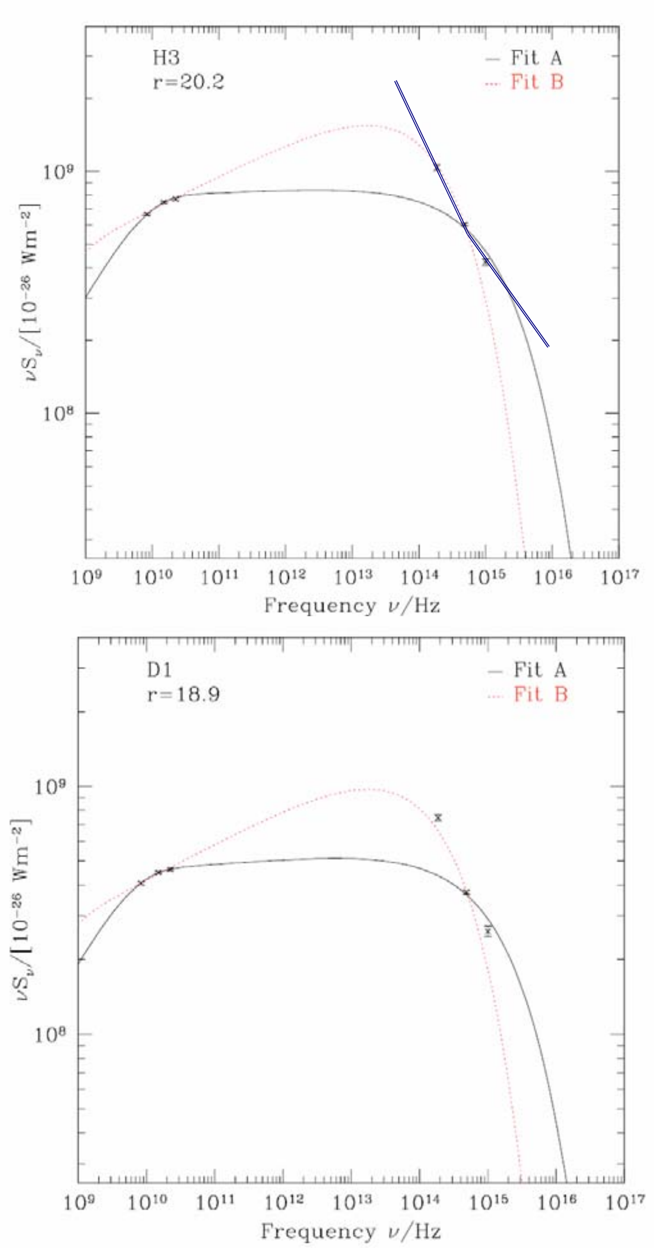
M87

top: M87 (Marshall, et al 2002)
bottom: 3C 273 (Marshall, et al. 2003)

GRB jet	AGN / (micro-) quasar jet
episodic	long-term → easier to study
face-on	face-on (blazar); oblique / edge-on
time-resolved: (slope F_ν) <1	bulk / limb-dominated → large Θ: (slope F_ν) <0
internal shocks	knots
external shock	hot spot; radio lobes

UV excess in 3C273 & M87





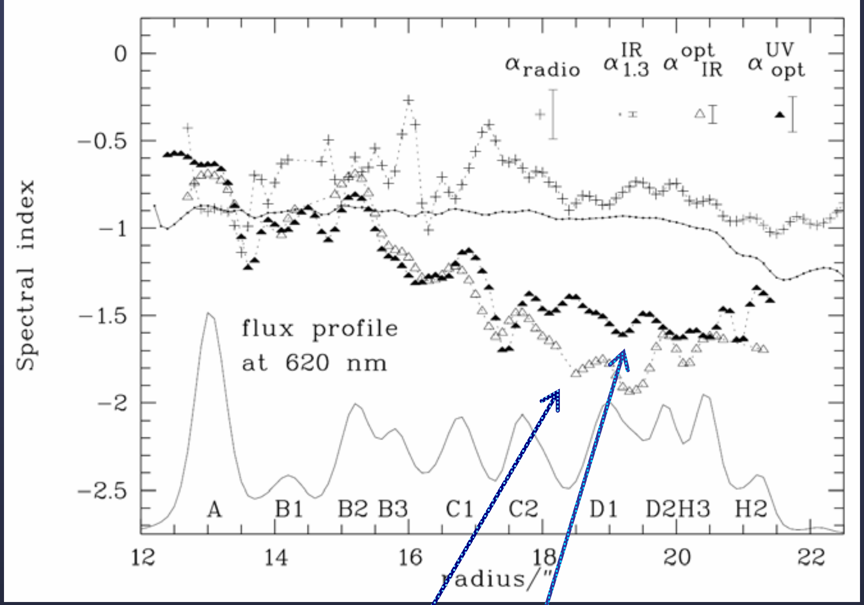
UV excess: $\alpha_{IR}^{opt} < \alpha_{opt}^{UV}$ (Jester, et al. AA, 2005)

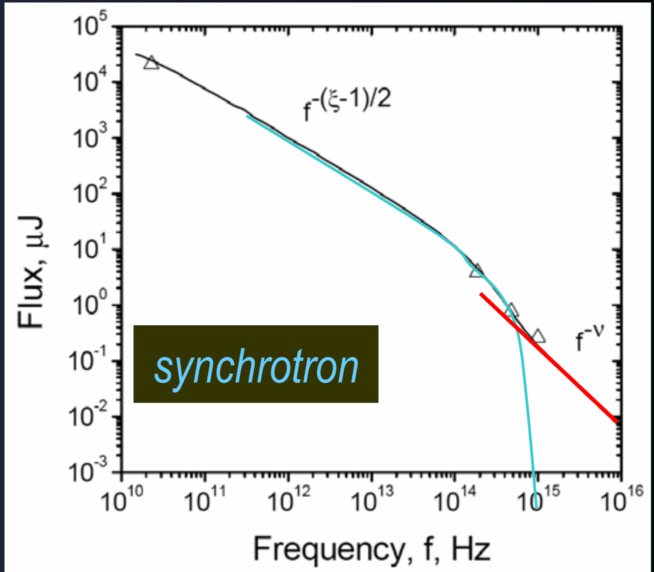
Interpretation:

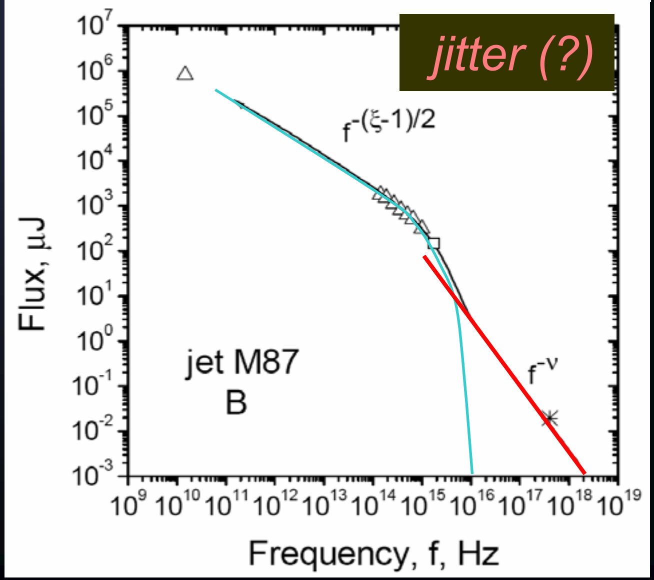
1) 2-component electron population or
2) Synchrotron + Jitter emission from same electrons

(Fleishman, astro-ph/0511353)

UV excess in 3C273 & M87







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Weibel in AGN jets

WEIBEL INSTABILITY:

✦ *occurs in **weakly magnetized** plasmas,* ← *AGN jets (likely) contain sub-equipartition, large-scale fields (!)*

$B^2/8\pi p < 0.02$ *(Spitkovski, 2005)*

✦ *no field generation at scales smaller than* k_{crit}

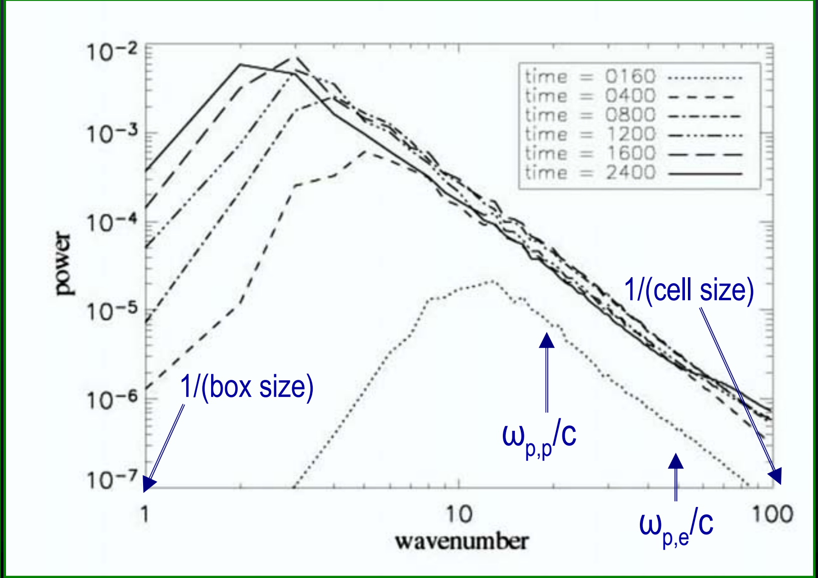
Weibel in AGN jets

WEIBEL INSTABILITY:

- occurs in **weakly magnetized** plasmas, $B^2/8\pi p < 0.02$ (Spitkovski, 2005)
- no field generation at scales smaller than k_{crit}

AGN jets (likely) contain sub-equipartition, large-scale fields (!)

PIC simulations are inconclusive about high-k spectrum

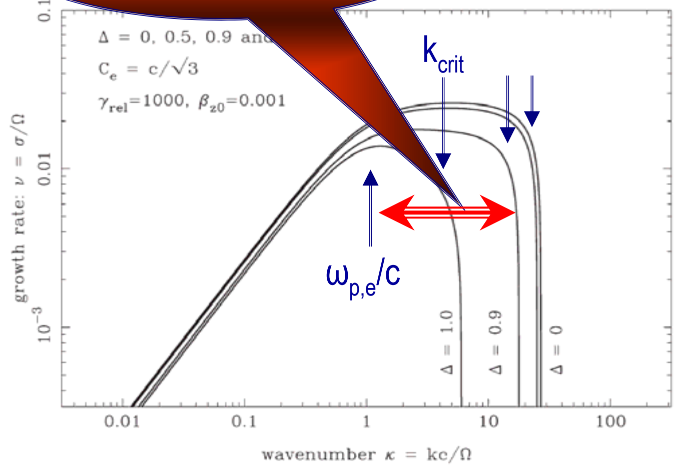


$$0 < k^2 < k^2_{\rm crit} \equiv \left(\frac{\omega_p^2}{\hat{\gamma} c^2}\right)\left[\frac{\beta_\parallel^2}{2\beta_\perp^2(1-\beta_\perp^2)} - G(\beta_\perp)\right],$$

where $G(\beta_\perp) = (2\beta_\perp)^{-1}\ln\left[(1+\beta_\perp)/(1-\beta_\perp)\right]$,

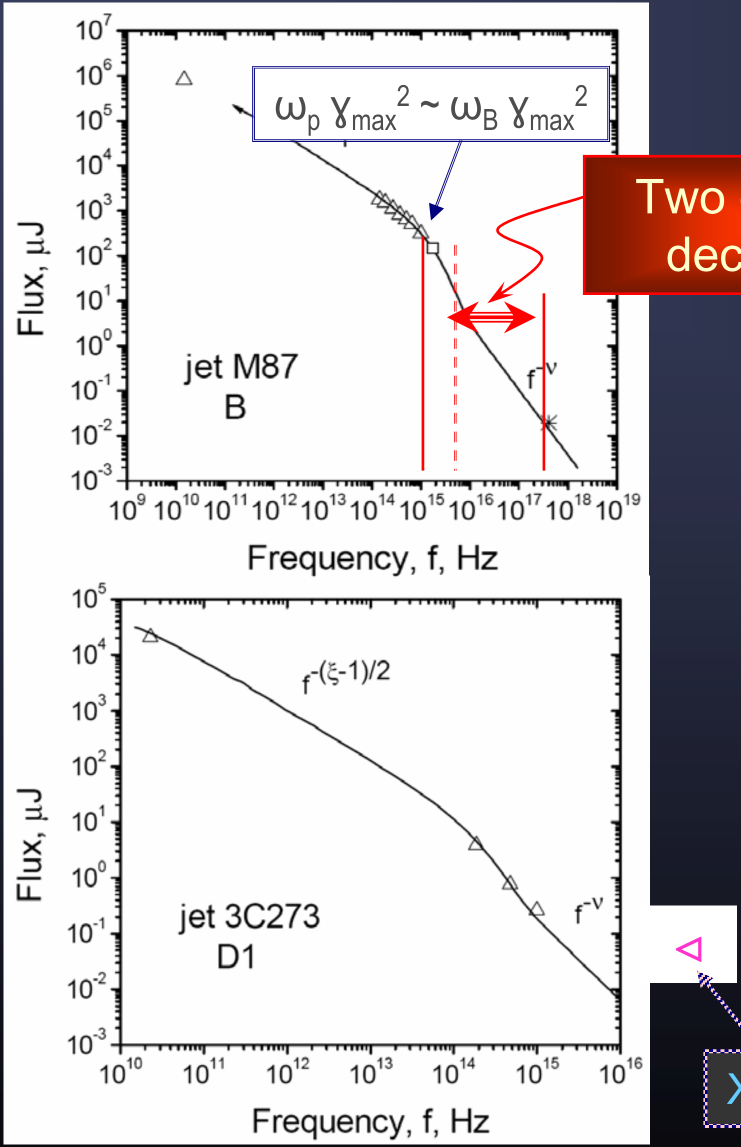
A decade between peak and cutoff

…nstability

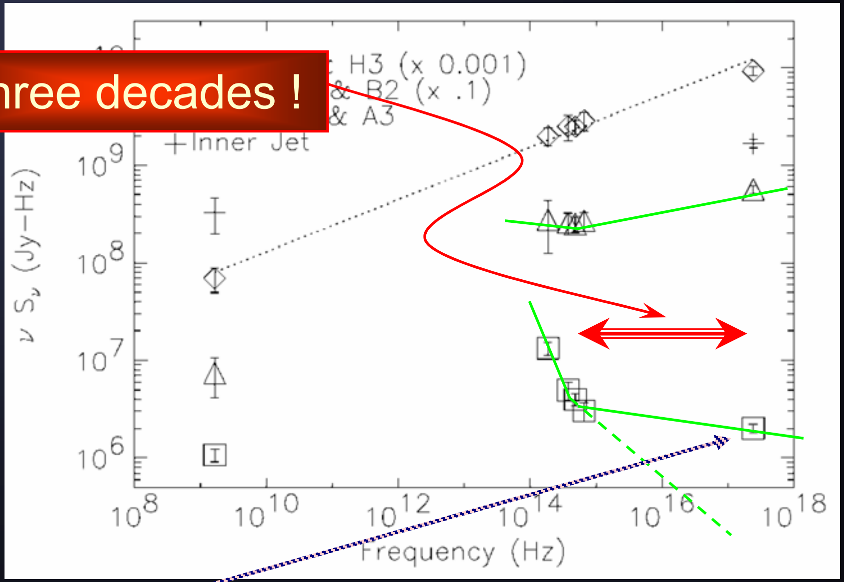


(Weirsma & Achtenberg, AA, 2004)

Can jitter explain UV excess?



Two or more decades !



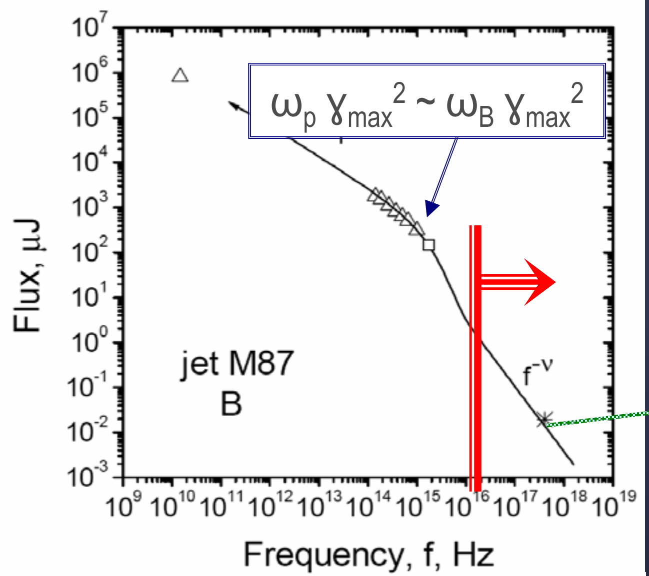
Three decades !

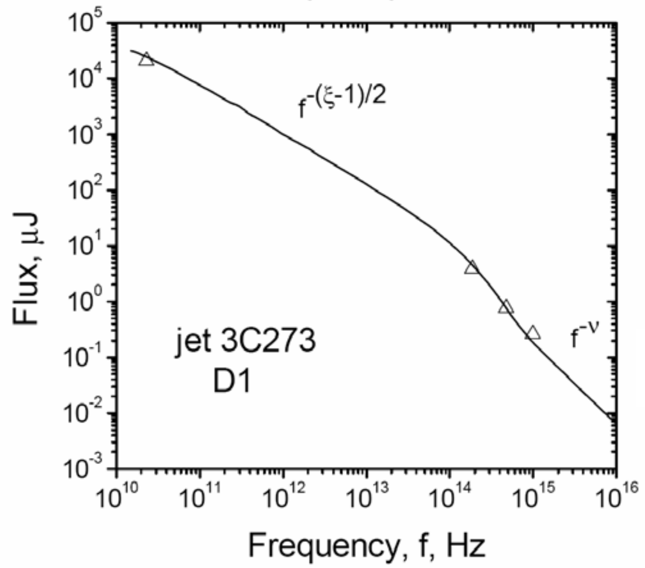
X-ray: Chandra

(Marshall, et al. 2001)

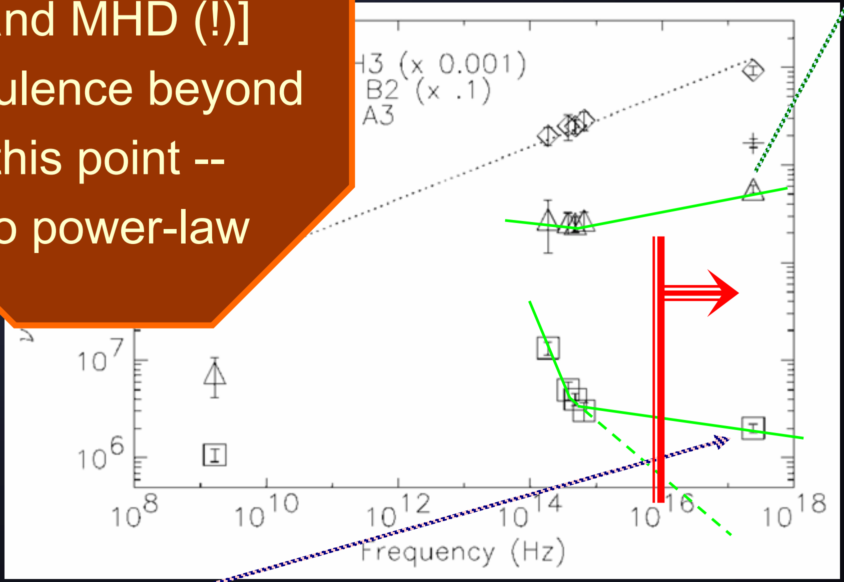
Can jitter explain UV excess?

To explain X-ray observations we need scales of B-field: $\lambda \leq 0.01\ c/\omega_p = 10$ m





No Weibel
[and MHD (!)]
turbulence beyond
this point --
no power-law



X-ray: Chandra

(Marshall, et al. 2001)

Outline

Effect of the shock geometry

- Introduction:
  Shock microphysics, Weibel turb nce, particle acceleration
- Radiation production at shocks
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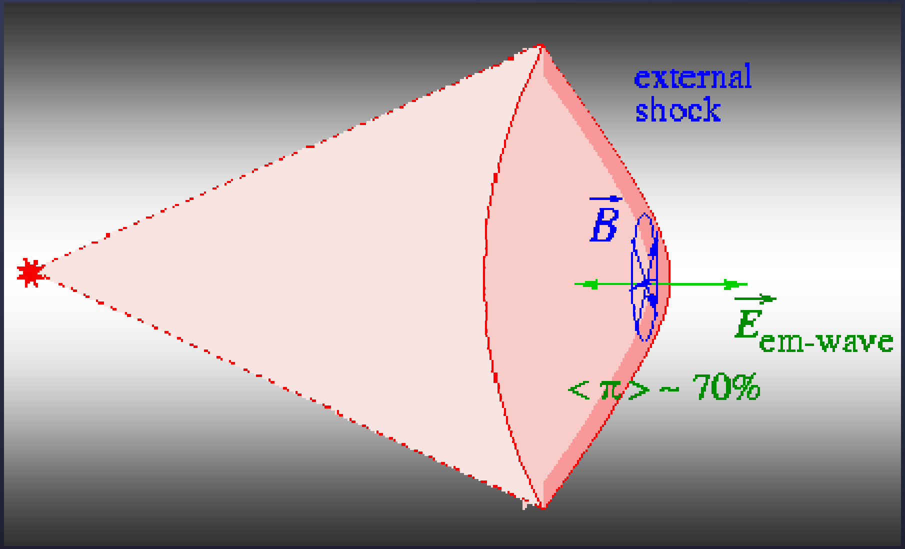
- Summary

Polarization from jets



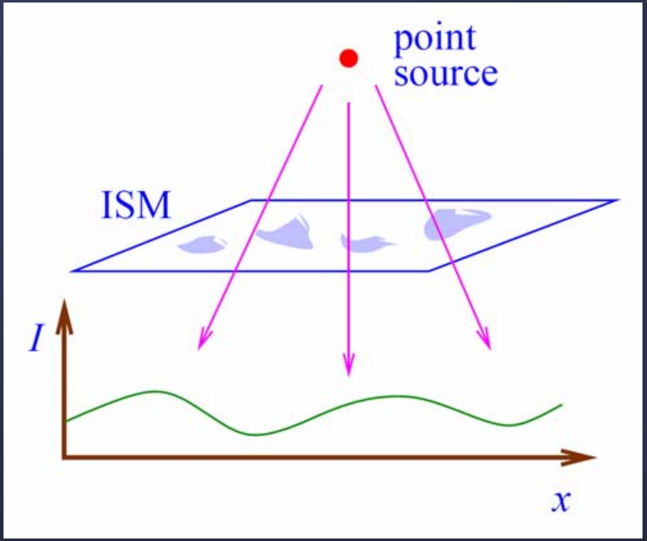
Beamed ejecta (jet)

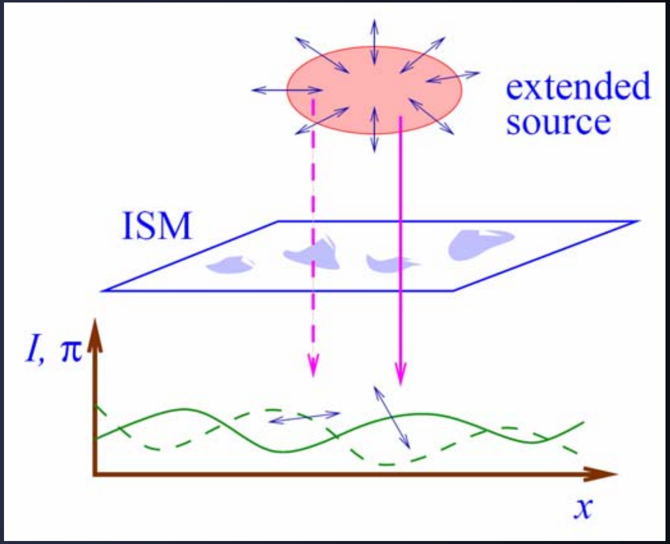
low polarization

high polarization

(Waxman, 2003; Granot, et al., 2003)

Polarization Scintillation





Intensity scintillations:

$\Theta_s < \Theta_{diff}$: $<\Delta I>$ - large

$\Theta_s > \Theta_{diff}$: $< I > = \text{const.}$

$<\Delta I>$ - small

Polarization scintillations:

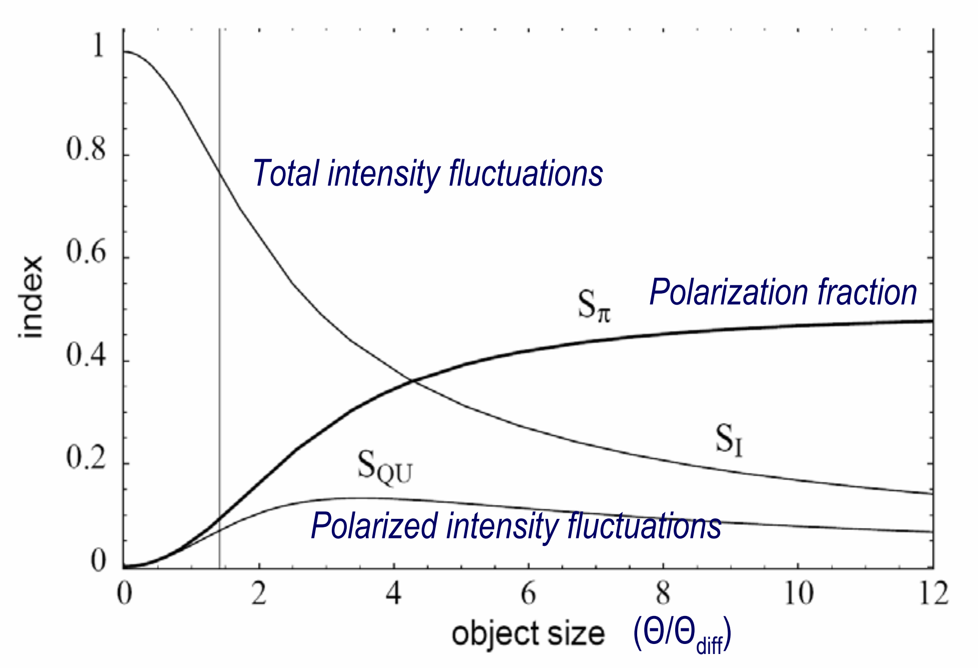
$\Theta_s < \Theta_{diff}$: $<\pi> = 0$

$<\Delta\pi>$ - small

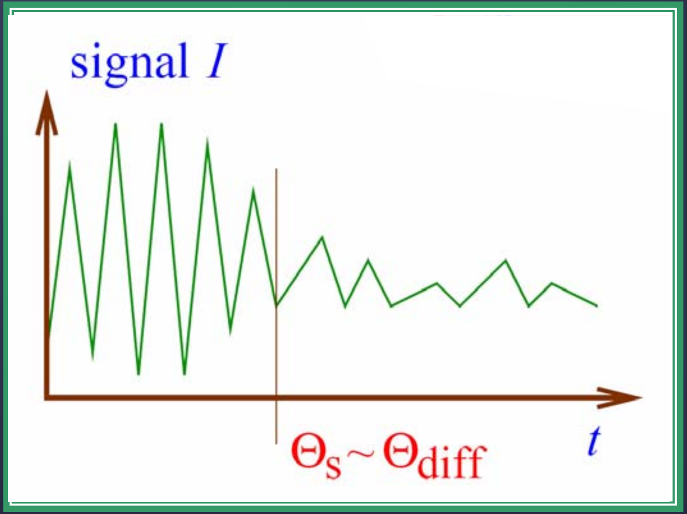
$\Theta_s > \Theta_{diff}$: $<\Delta\pi>$ - large

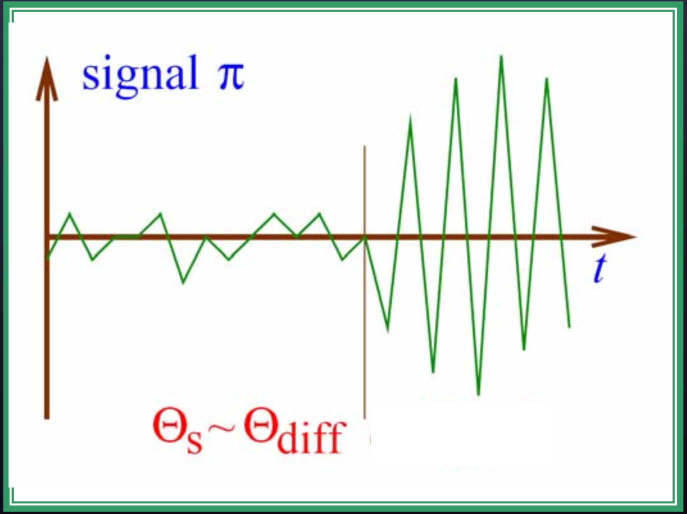
(Medvedev & Loeb 1999; Medvedev 2000)

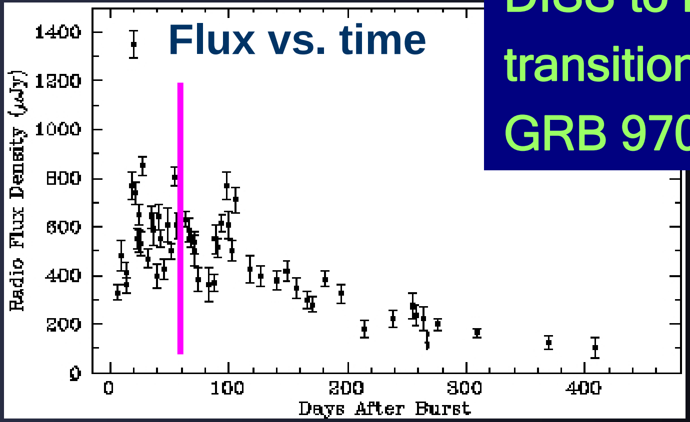
Polarization Scintillation



Polarization Scintillaton: observ.







DISS to RISS transition in GRB 970508

(Frail, Waxman, Kulkarni 1999)

GRBs: no detection yet; upper limit : $\pi < 10\%$

AGNs: intra-day variability (?!)

Summary

- "Weibel shocks" (small-scale B-field)
- Jitter radiation theory
- for GRBs :
  - violation of the Synchrotron LoD, $\alpha > -1/3$
  - sharp spectral peaks
  - possible spectral featured
  - *flux*-α correlation (*hardness-intensity* correlation)
  - peak of α distribution at $\alpha \sim -1$
  - Diffusive Synchrotron → fails for Weibel fields
  - spectral variability (+*"tracking"* behavior)
- AGN and GRB jets
  - jitter from AGN jets → *use caution*
  - net polarization
  - polarization scintillations → *intraday variability*