Jitter Radiation： VHE GRBs

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IACT Observations to TeV-GRBs

- GRB 190114C – MAGIC
- GRB 180720B – H.E.S.S.
- GRB 190829A – H.E.S.S.

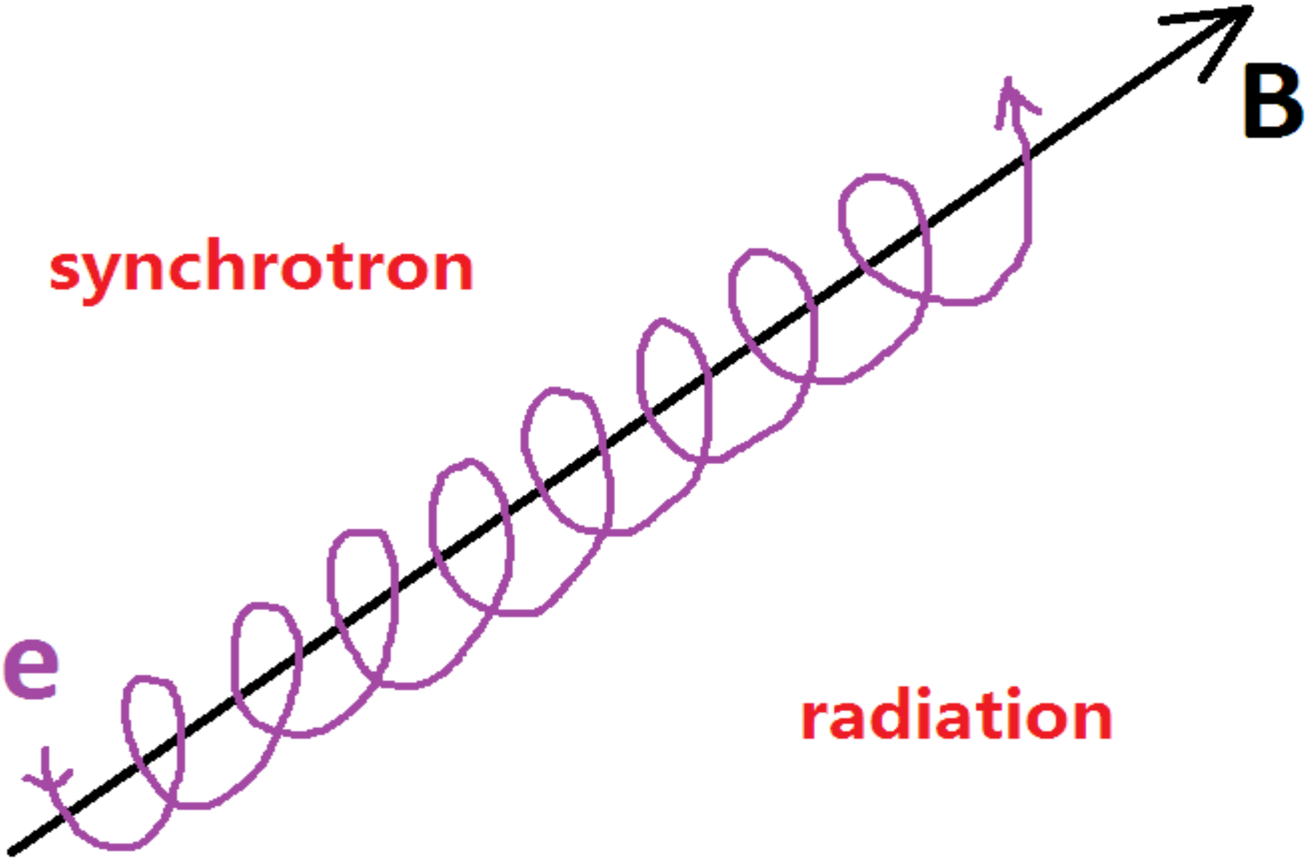
Synchrotron Limit & IC/SSC

- Synchrotron limit 160 MeV
  relativistic boosting 100-1000
  hard to reach TeV energy band

- Inverse Compton scattering or
  Synchrotron Self-Compton

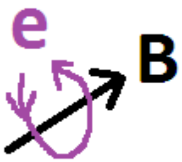
Alternative Scenario

- Jitter radiation to explain TeV GRBs



synchrotron

radiation



still cyclotron/synchrotron moving?

electron random walk inside

random & small-scale fields

special case: electron "collision"
with magnetic elements keeping
same velocity direction
---- jitter radiation

Synchrotron vs Jitter

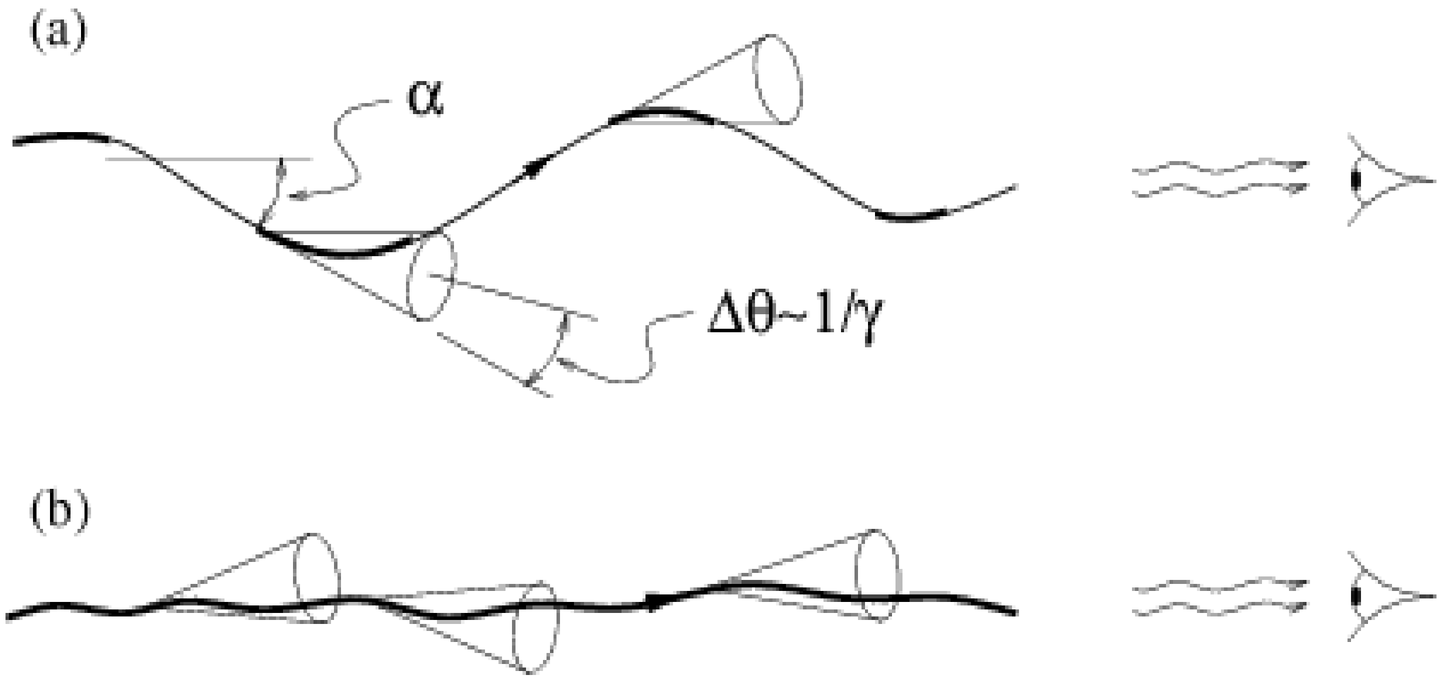


FIG. 1.— Emission from various points along particle's trajectory; (a) — $\alpha \gg \Delta\theta$, emission from selected parts (bold portions) of the trajectory is seen by an observer, (b) — $\alpha \ll \Delta\theta$, emission from the entire trajectory is observed.

Synchrotron vs Jitter

- Relativistic electrons in ordered and large-scale magnetic field:

Synchrotron

- Relativistic electrons radiation in random and small-scale magnetic field:

Jitter

Jitter Regime

- Radiation by a single relativistic particle in small scale magnetic field (Landau & Lifshitz 1971):

$$I_{\omega} = \frac{2\pi e^{2}}{c^{3}} \int_{1/2\gamma_{*}^{2}}^{\infty} \left(\frac{\omega}{\omega'}\right)^{2} \left|w_{\omega'}\right|^{2} \left(1 - \frac{\omega}{\omega'\gamma_{*}^{2}} + \frac{\omega^{2}}{2\omega'^{2}\gamma_{*}^{4}}\right) d\left(\frac{\omega'}{\omega}\right)$$

$$I_{\omega} = \frac{e^{4}}{m^{2}c^{3}\gamma^{2}} \int_{1/2\gamma_{*}^{2}}^{\infty} d\left(\frac{\omega'}{\omega}\right)\left(\frac{\omega}{\omega'}\right)^{2}\left(1 - \frac{\omega}{\omega'\gamma_{*}^{2}} + \frac{\omega^{2}}{2\omega'^{2}\gamma_{*}^{4}}\right) \int dq_{0}\, dq\, \delta(\omega' - q_{0} + qv) K(q) \delta(q_{0} - q_{0}(q))$$

Perturbation Theory

- Radiation is related to perturbation

$$\omega' = q_0 - \mathbf{q}\mathbf{v}$$

- Dispersion relation (e.g., collisionless shock)

$$q_0 = cq[(1 \pm \sqrt{1 + 4\omega_{pe}/c^2q^2\gamma^2})/2]^{1/2}$$

- Maximum radiative frequency

$$\omega_{max} = \gamma^2 c q_{max}$$

Radiative Frequency

- Prandtl number

$$P_r = 10^{-5} T_e^4 / n$$

- Turbulent lengthscale

$$P_r^{1/2} = q_\eta / q_\nu \quad q_\nu = 2\pi l_{eddy}^{-1} = 2\pi (R/\Gamma_{sh}\gamma_t)^{-1}$$

- Maximum radiative frequency

$$\omega = 4.9\left(\frac{n}{3.0 \times 10^{10}\mathrm{cm}^{-3}}\right)^{-1/2}\left(\frac{T_e}{5.9 \times 10^{9}\mathrm{K}}\right)^{2}\left(\frac{R}{1.0 \times 10^{13}\mathrm{cm}}\right)^{-1}\left(\frac{\Gamma_{sh}}{100.0}\right)\left(\frac{\gamma_t}{10.0}\right)\left(\frac{\gamma}{1.0 \times 10^{7}}\right)^{2}\ \mathrm{TeV}$$

Radiative Spectrum

- power-law spectrum

$$I_\omega = \frac{4e^4}{3(\zeta_p - 1)m_e^2 c^{4-\zeta_p}} \gamma^{2(\zeta_p - 1)} \omega^{-(\zeta_p - 1)}$$

- Spectral index $\zeta_p - 1$ related to turbulent spectral index $F(q) \propto q^{-\zeta_p}$

- magnetic field $\langle \delta B^2(q) \rangle \sim K(q) \sim \int_q^\infty F(q')dq'$

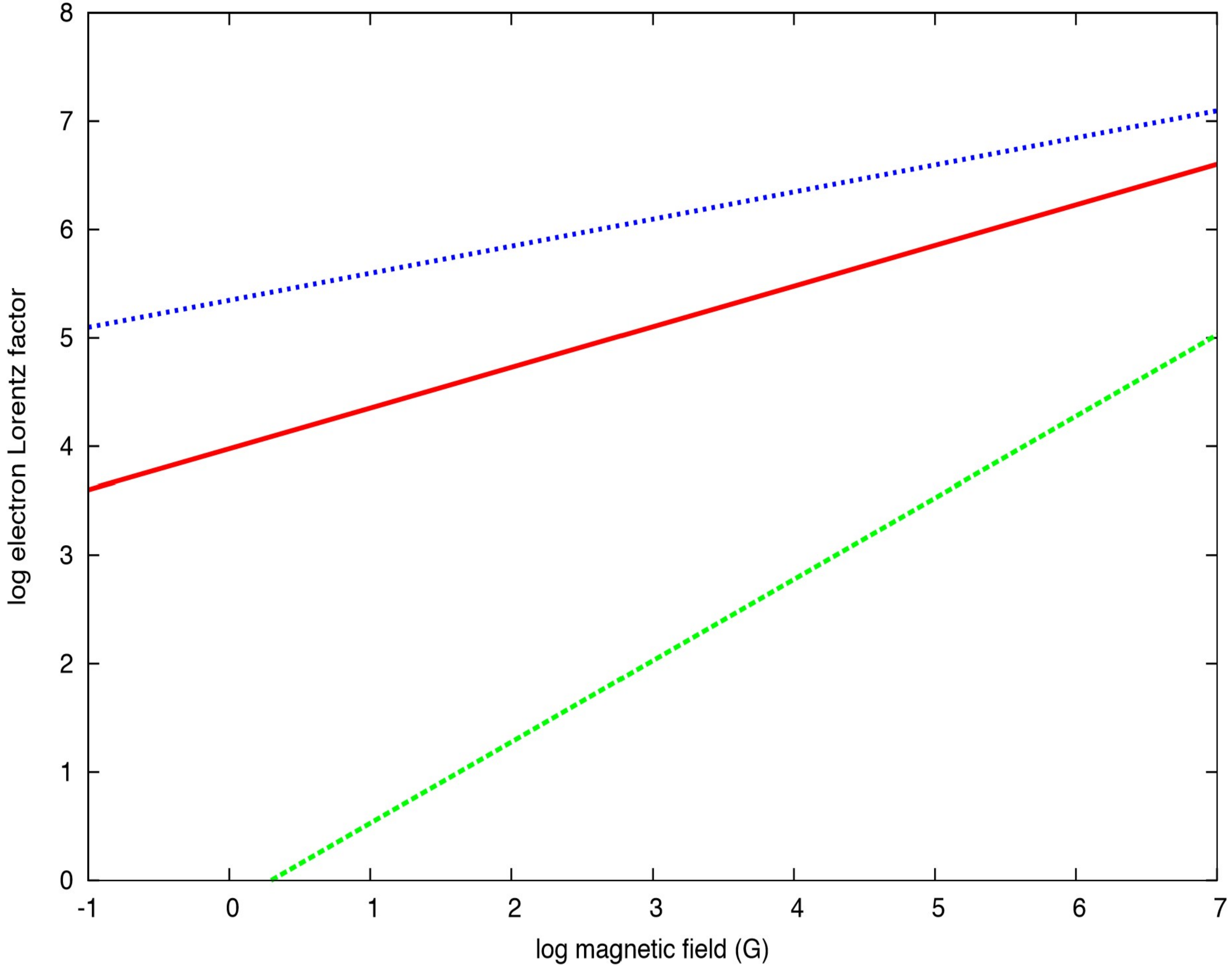
Electron Radiative Cooling

- acceleration in electromagnetic field

$$\omega I_\omega = ecB$$

- Electron Lorentz factor with cooling

$$\gamma = [\frac{3(\zeta_p - 1)m_e^2 c^{5-\zeta_p} B\omega^{\zeta_p - 2}}{4e^3}]^{\frac{1}{2(\zeta_p - 1)}}$$


log electron Lorentz factor
log magnetic field (G)
0
1
2
3
4
5
6
7
8
-1
0
1
2
3
4
5
6
7

Particle Acceleration

- Electron Lorentz Factor

$$\gamma_{max,e} = eEL/m_ec^2 = 5.9 \times 10^{11}(\frac{R}{10^{13}\mathrm{cm}})(\frac{B}{1.0 \times 10^6 G})(\frac{\Gamma_{sh}}{100.0})^{-2}$$

- Proton Lorentz Factor

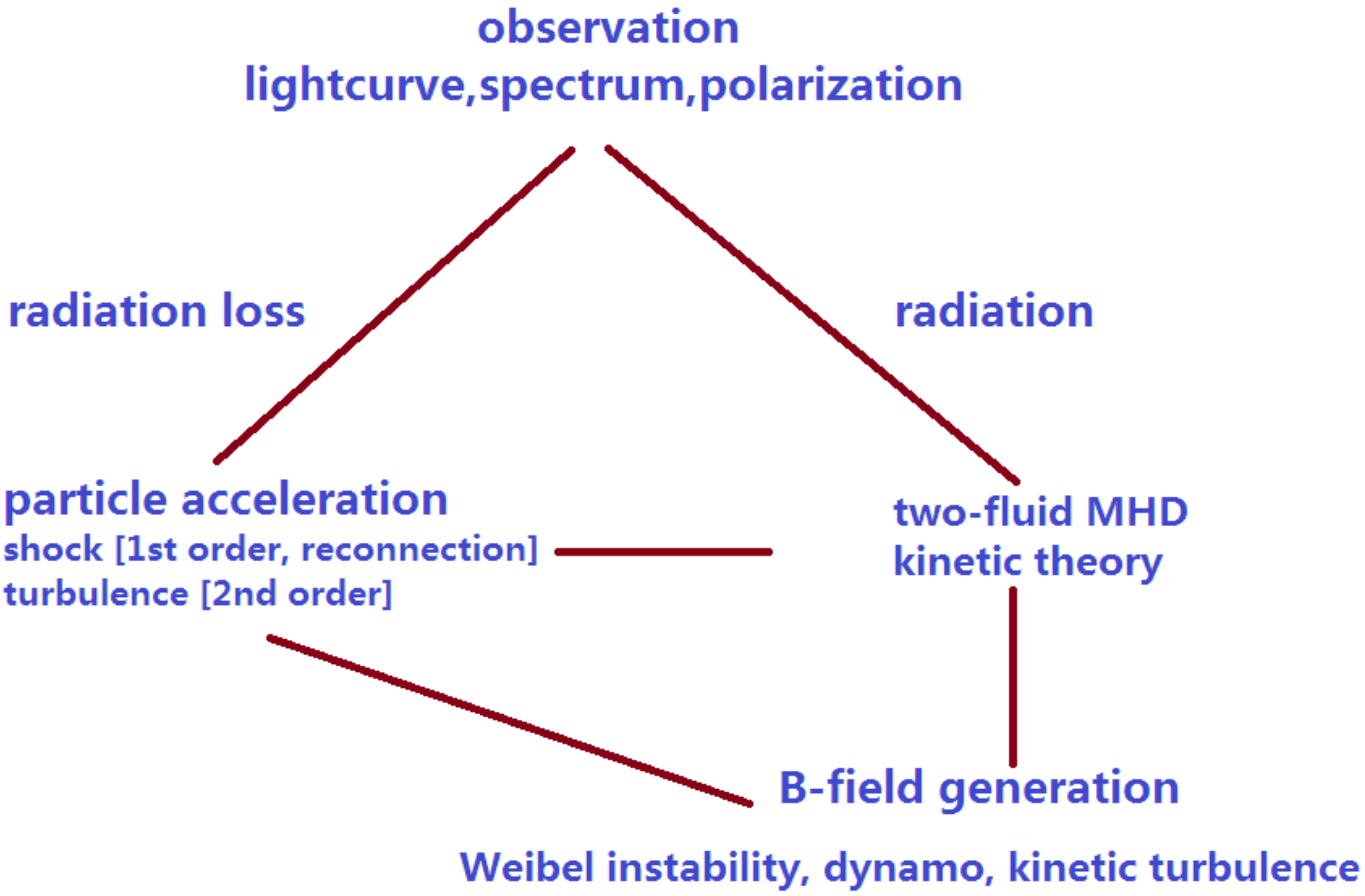
$$\gamma_{max,p} = eEL/m_pc^2 = 3.2 \times 10^{8}(\frac{R}{10^{13}\mathrm{cm}})(\frac{B}{1.0 \times 10^6 G})(\frac{\Gamma_{sh}}{100.0})^{-2}$$

Conclusion

- Jitter can produce TeV photons of GRBs

  (suitable for prompt emission and afterglow)
- Turbulence reach kinetic lengthscale

  Kinetic Alfven wave may work as an example
- Radiative spectral index is decided by turbulent spectral index
- Plasma properties at the kinetic lengthscale
- Multiwavelngth research is necessary
- Other TeV sources： blazars
- LHAASO survey can promptly detect TeV-GRBs



observation
lightcurve,spectrum,polarization

radiation loss

radiation

particle acceleration
shock [1st order, reconnection]
turbulence [2nd order]

two-fluid MHD
kinetic theory

B-field generation

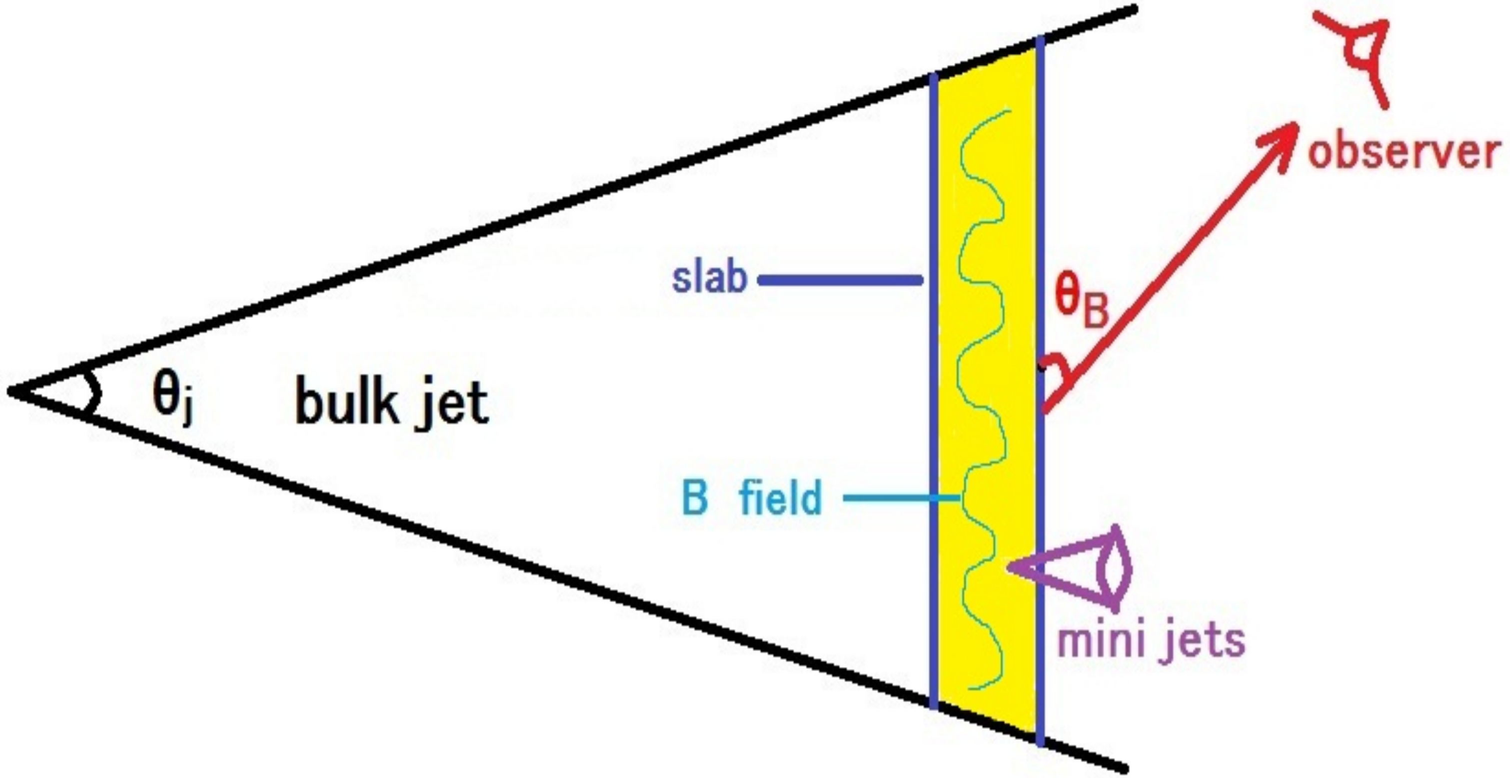
Weibel instability, dynamo, kinetic turbulence

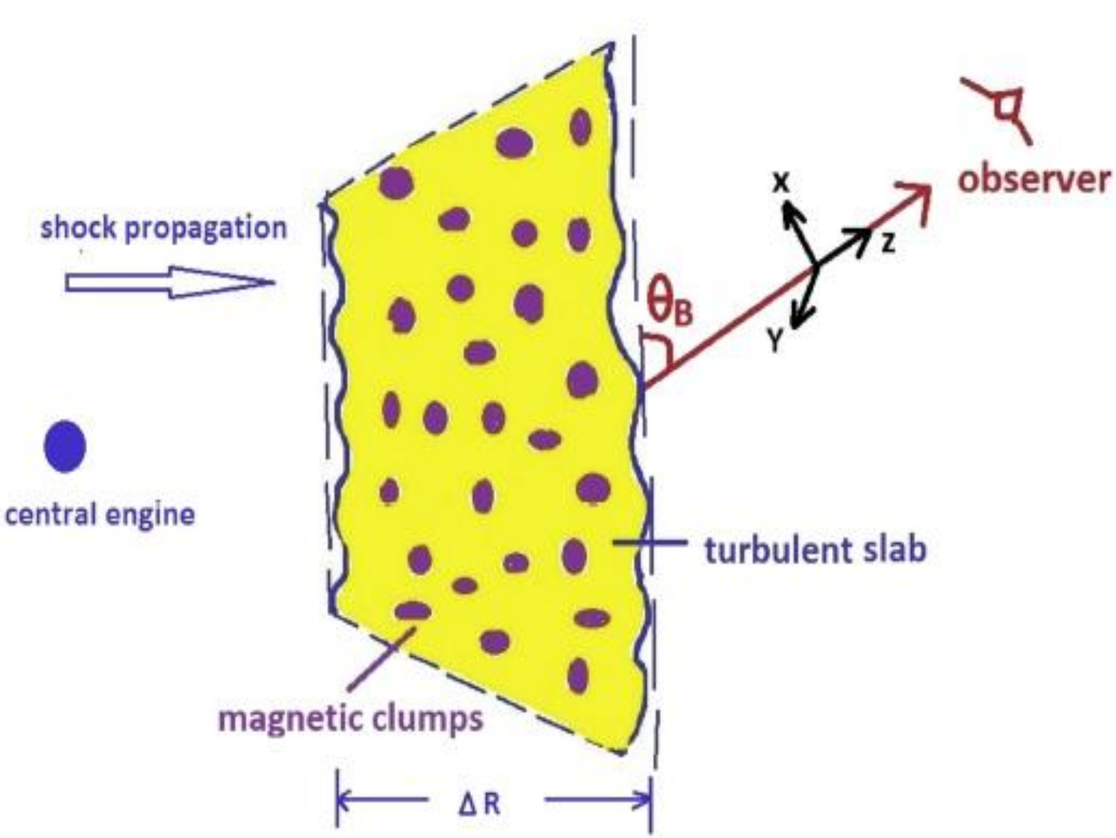
Inverse Compton Scattering

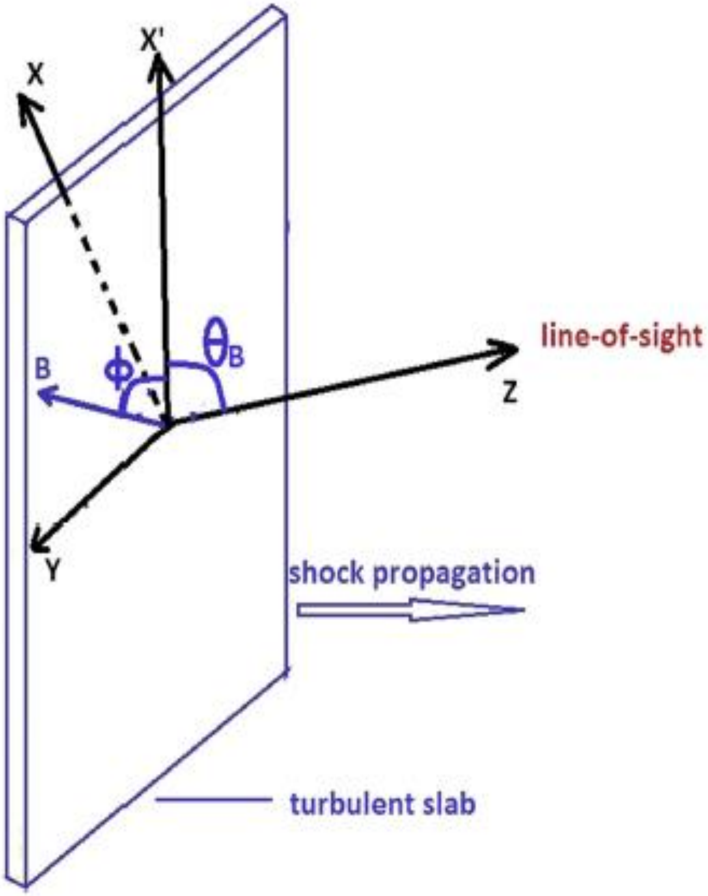
- We do not rule out IC process

- If we consider Synchrotron Self-Compton
  we can also consider jitter self-Compton

Magnetic Slab & Jet-in-jet

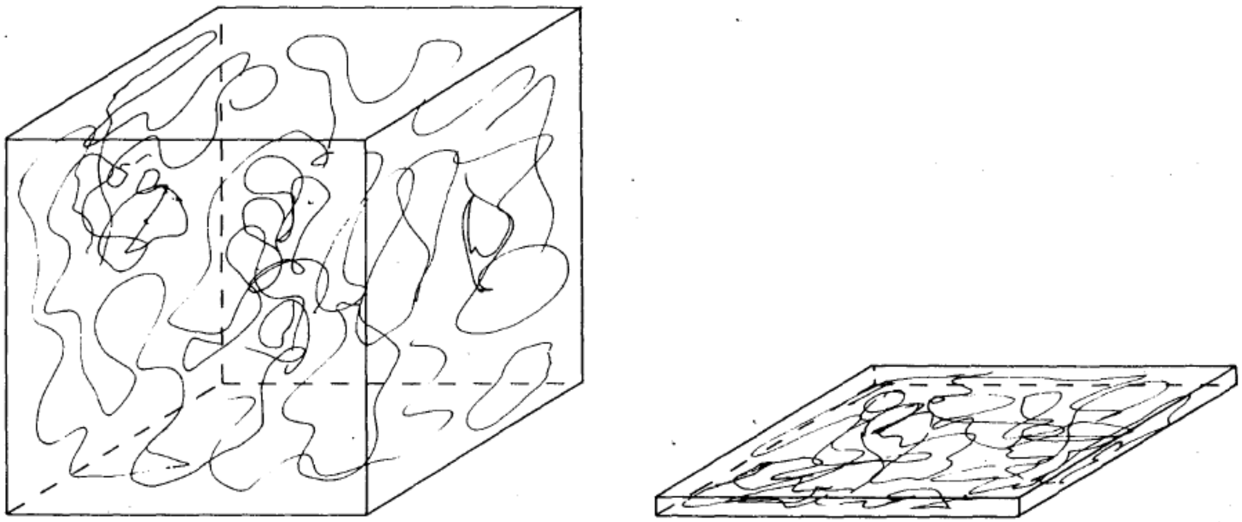



shock propagation
central engine
magnetic clumps
ΔR
turbulent slab
θB
x
z
Y
observer


X
X'
B
ϕ
θB
line-of-sight
Z
Y
shock propagation
turbulent slab

B-field Topology

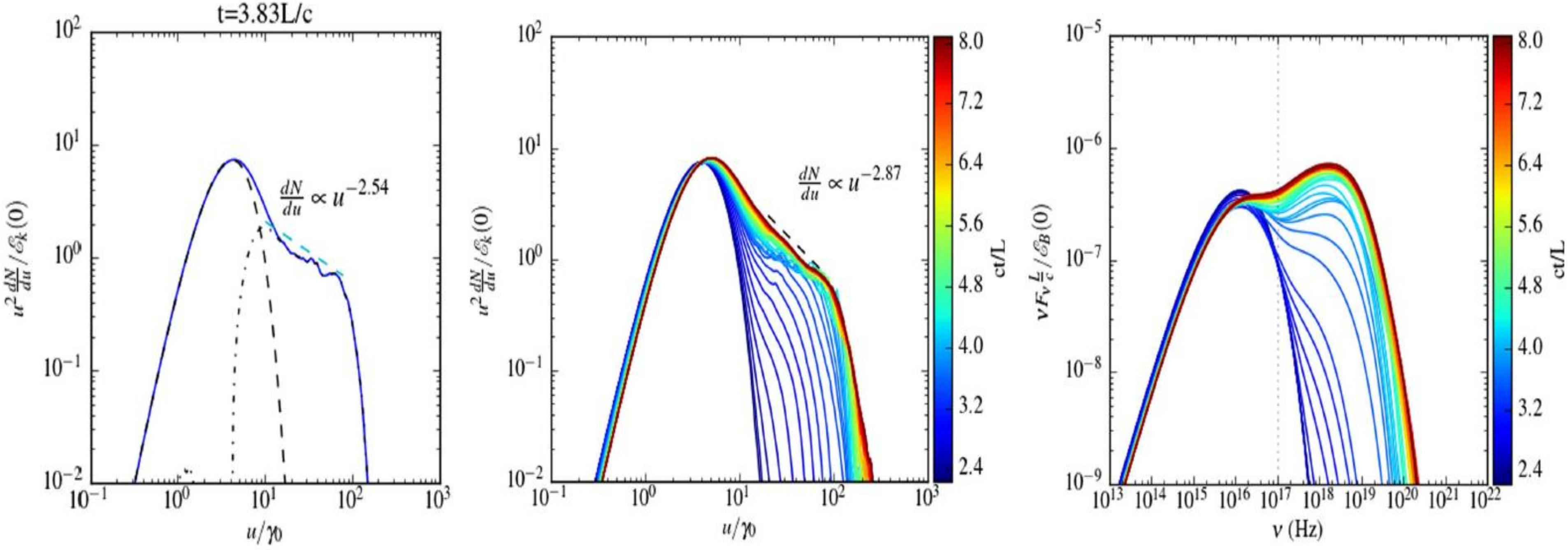
- Compressed magnetic slab (Laing 1980, 2002)



$$B_x = B_0 \cos\phi \sin\vartheta_B, B_y = B_0 \sin\phi, B_z = B_0 \cos\phi \cos\vartheta_B$$

$$B = B_0 (\cos^2\phi \sin^2\vartheta_B + \sin^2\phi)^{1/2}$$

Electron Energy Distribution：Kinetic Scale



Nalewajko et al. (2015)