Gamma ray Bursts powered by turbulence and reconnection

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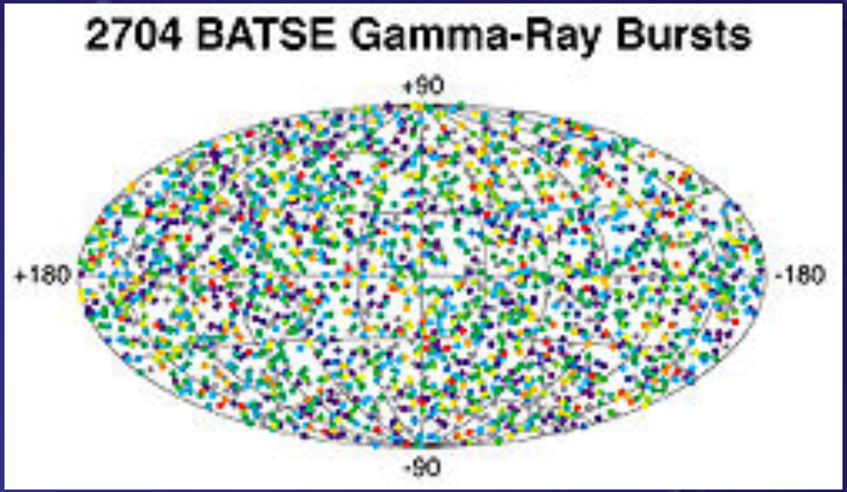
References:

Lazarian, Petrosian, Yan & Cho, 2003;

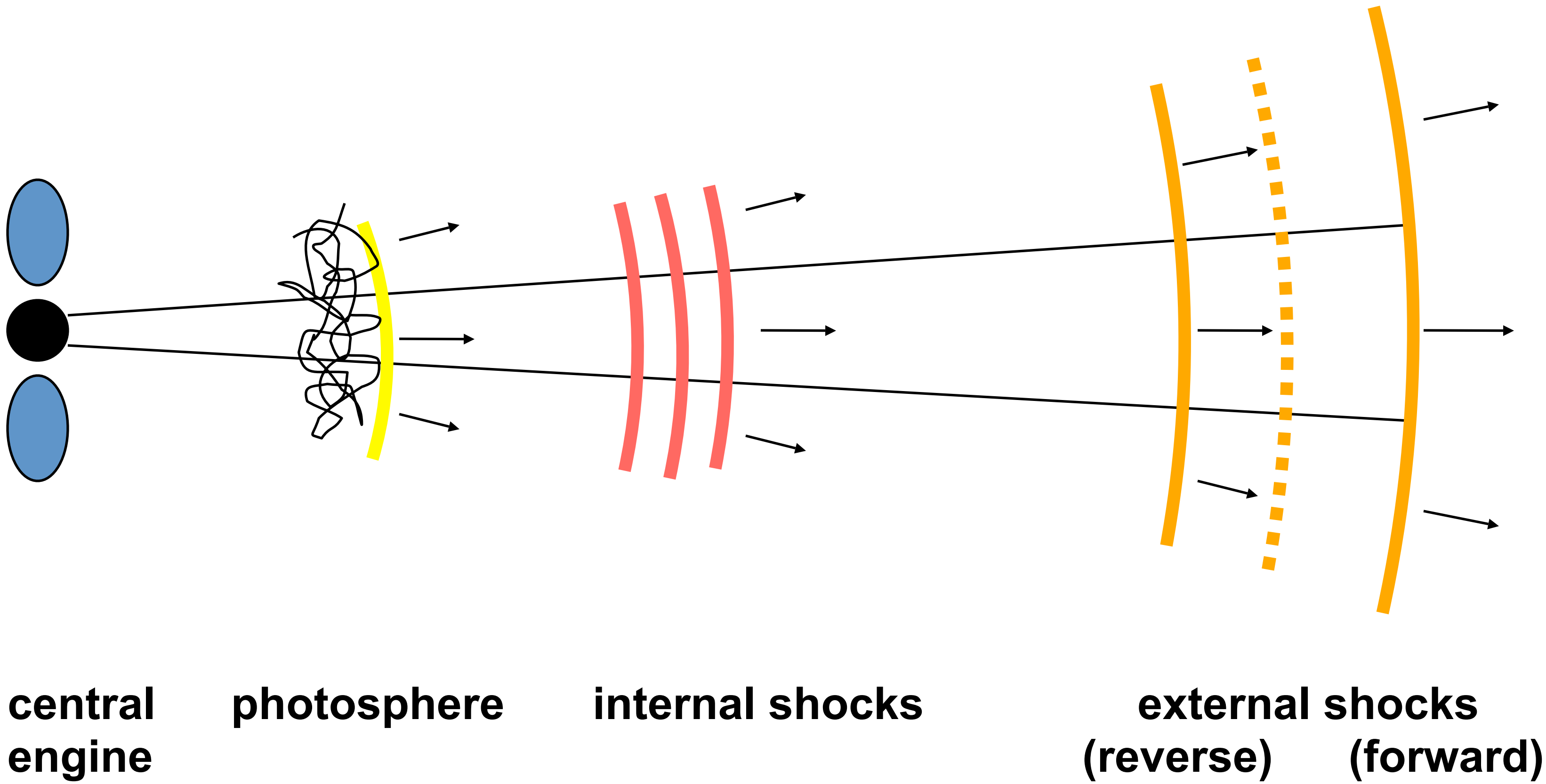
Zhang & Yan 2011

GRBs: brightest electromagnetic event in the universe!



A typical burst releases as much energy in a few seconds as the Sun will in its entire 10-billion-year lifetime. Extragalactic origin with record redshift up to $z \sim 8$.

Standard Fireball Shock Model



GRB prompt emission: from internal shocks and photosphere
Afterglow: from external shocks

Internal shock (IS) model

- collisions between mini shells launched from central engine create relativistic shocks

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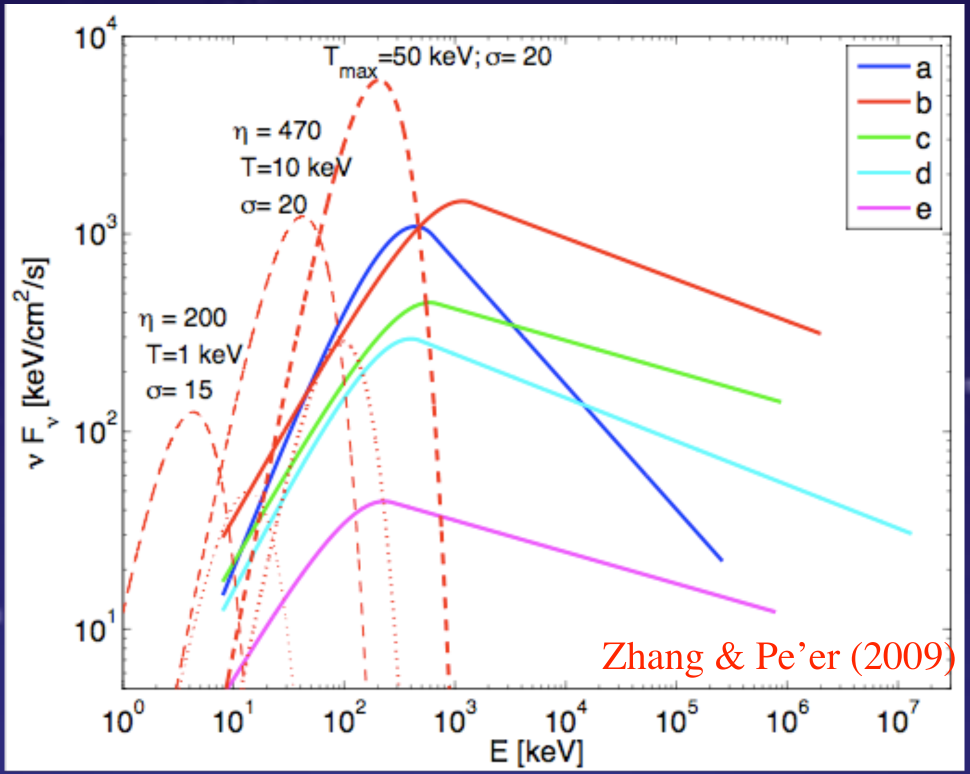
✗ Missing photosphere: thermal emission is missing

Expected photosphere emission from a fireball

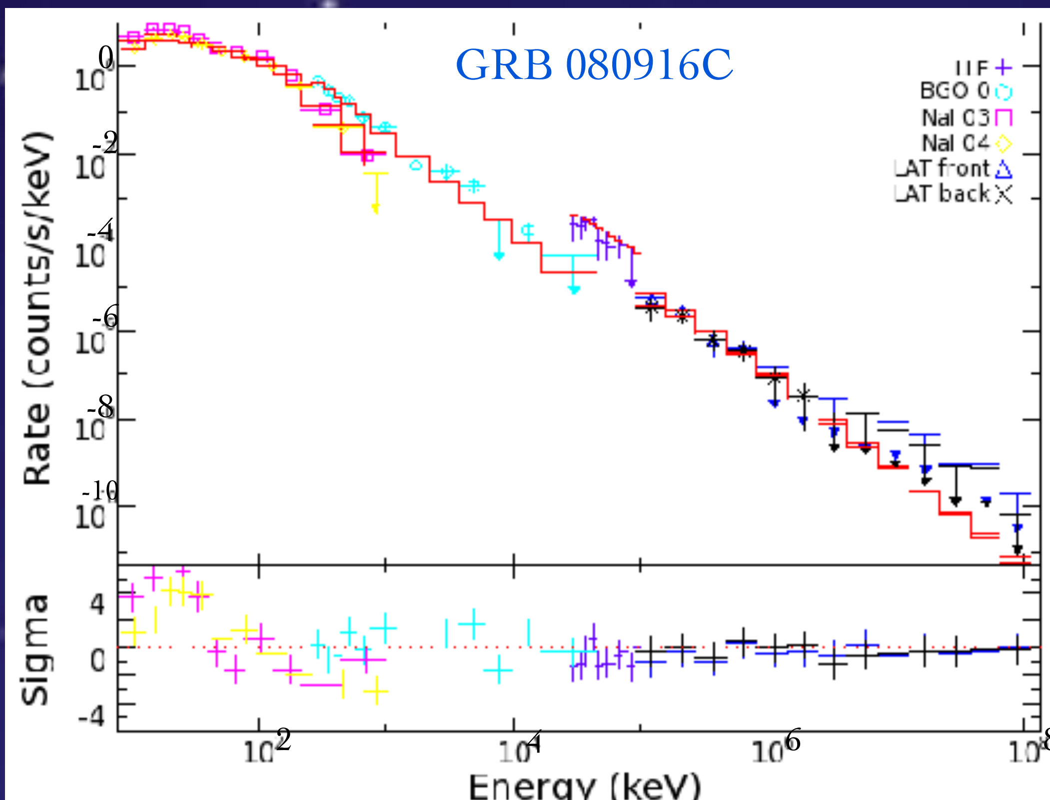


Sigma: ratio between Poynting flux and baryonic flux:

$\sigma \Xi F_P/F_b$: at least ~ 20, 15 for GRB 080916C

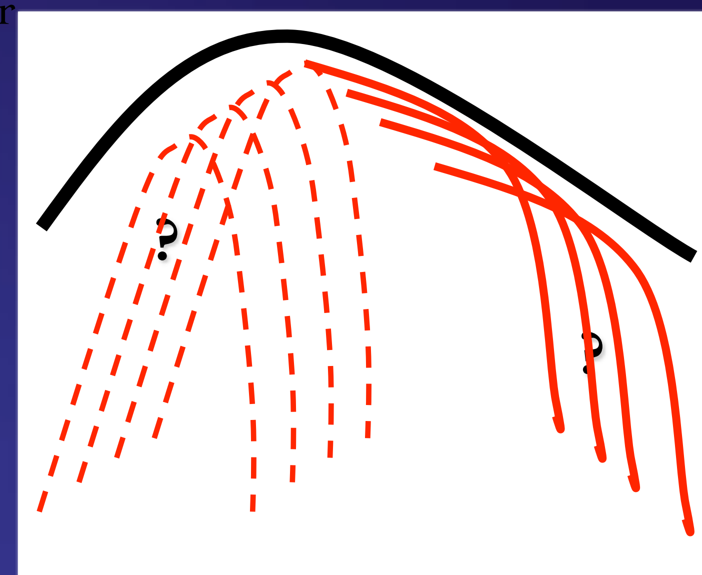
Confirmed by Fan (2010) with a wider parameter space study.

Is the band function emission from the photosphere?



Abdo et al. (2009)

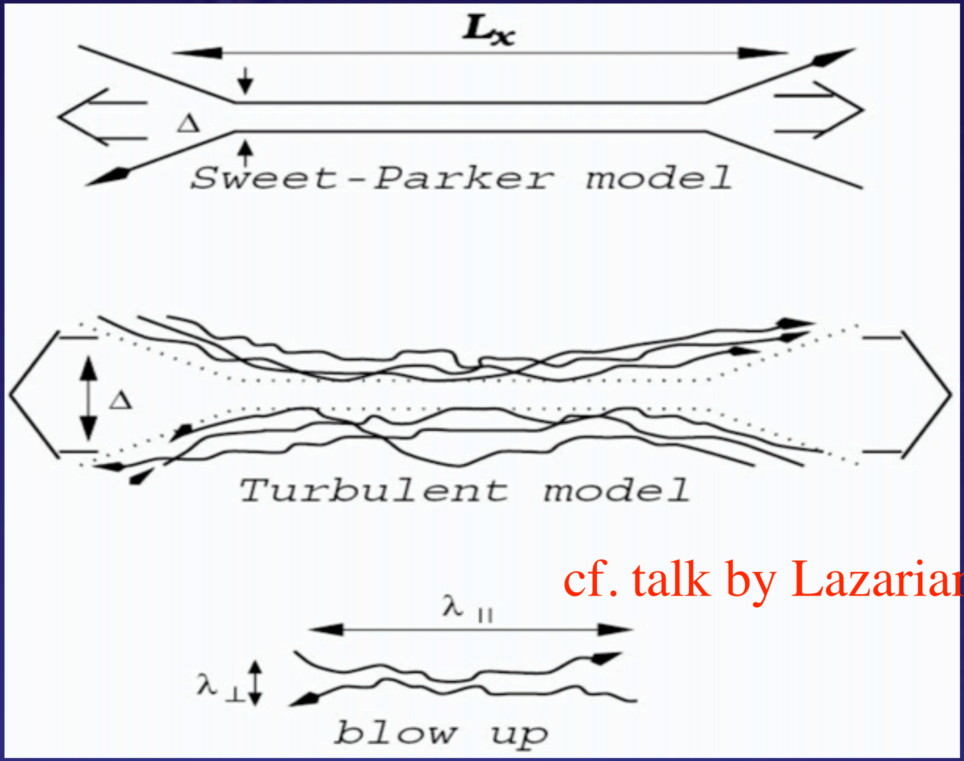
- Superposition from many shells (Toma et al. 2010; Li 2009)?
  - Contrived fine-tuning
  - Seems not supported by data with finer temporal resolution



GRBs powered by reconnection

- Highly magnetized GRBs have been suggested by observations. Magnetic energy is the natural reservoir of energy
- In the presence of turbulence, reconnection is expedited depending on the level of turbulence

Fast Reconnection in Turbulence



cf. talk by Lazarian

$$V_r, up = V_A \min\left[\left(\frac{l}{L_x}\right)^{1/2}, \left(\frac{l}{L_x}\right)^{1/2}\right] M_A^2$$

l - turbulence injection scale

M_A - Alfven Mach number

(Lazarian & Vishniac 1999)

New scenario: turbulence reconnection mechanism

(Lazarian, Petrosian Yan & Cho 2003)

- Reconnection rate can be both slow and fast, naturally explains the episodic feature observed in GRBs.
- Fast bursty reconnection eventually occurs as a nonlinear feedback of the increased stochasticity of the B field lines.
- The reconnection events start from limited volumes and then spread in the form of a chain reaction as the energy is fed back to the turbulence and induces dramatic change in the magnetic field topology.

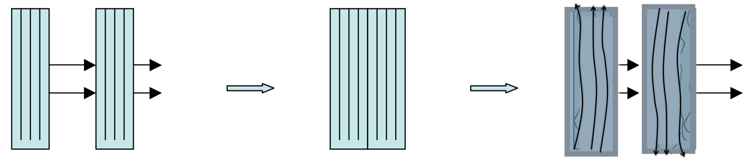
A New Model in the High-σ Regime: The ICMART Model

(Internal Collision-induced MAgnetic Reconnection & Turbulence, Zhang & Yan 2011)

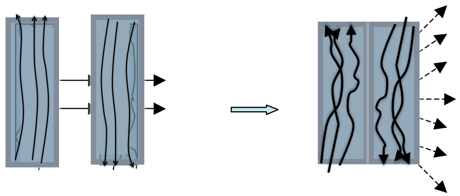
Basic Assumptions:

- The central engine launches a high-σ flow. The σ is still ~ (10-100) at R ~ 10^{15} cm.
- The central engine is intermittent, launching an outflow with variable Lorentz factors (less variable in σ).

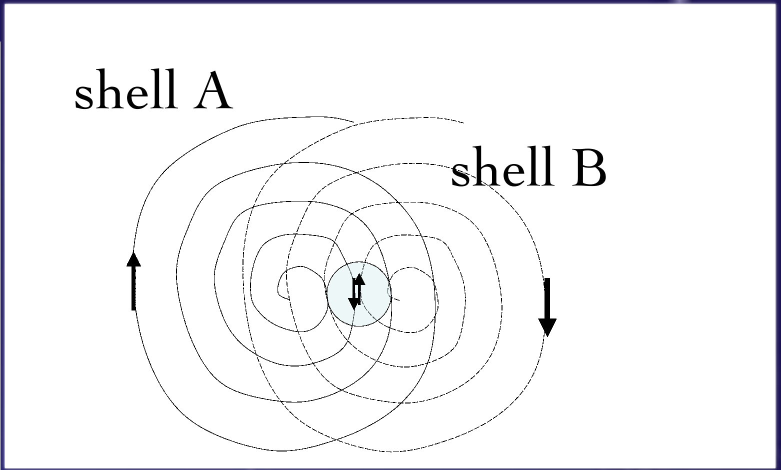
ICMART MODEL



(a) Initial collisions only distort magnetic fields

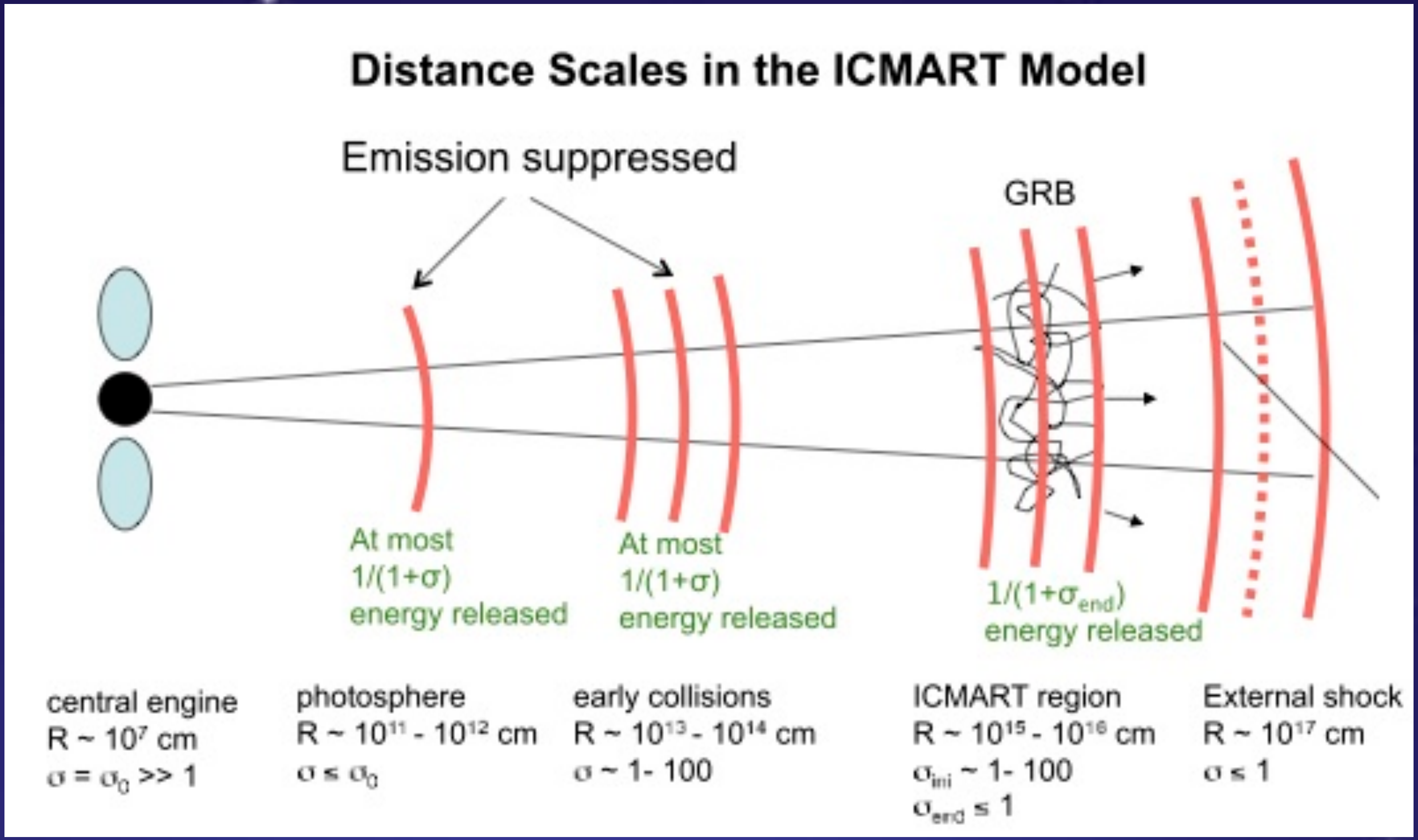


(b) Finally a collision results in an ICMART event



Astrophysical systems are not perfectly symmetric systems. For example, current-driven kink instability may develop in the jet (e.g., Mizuno et al. 2009a), which would introduce a slight misalignment of the magnetic field axes in two consecutive “shells.” This would result in a small cross section near the magnetic axes that have opposite orientations in the two shells

Fast reconnection triggers a GRB at large R



Turbulent Reconnection is needed to power GRBs

In order to reach GRB luminosity, the effective global reconnection rate has to be close to *c* .

$$\Gamma^2 \frac{B'^2}{8\pi} 4\pi R^2 \frac{\Delta'}{\Delta t'} \sim L_\gamma \quad \Longrightarrow \quad V'_{rec,global} = \frac{\Delta'}{\Delta t'} \sim \frac{L_\gamma}{L_w} \frac{1+\sigma}{\sigma} c \sim c$$

Relativistic Sweet-Parker reconnection speed is << *c* (Lyubarsky 2005).

$$V'_{rec,local} = V_A s^{-1/2} << c \qquad s \equiv \frac{\lambda V_A}{\eta} >> 1$$

Turbulent reconnection (Lazarian & Vishniac 1999) can become comparable to Alfven speed and close to c with sufficient turbulence developed in the relativistic regime (cf. Cho's talk).

Comparison of the models

	IS model	ICMART	
variability from central engine	✔	✔	
High efficiency	✗	✔	~ 50%
fast cooling problem	✗	✔	turbulence heating
Electron Excess problem	✗	✔	
missing photosphere	✗	✔	

Difference from other models

The EM model proposed by Lyutikov & Blandford (2003)

- invokes an extremely high-σ ($\sigma > 10^6$) at the deceleration radius

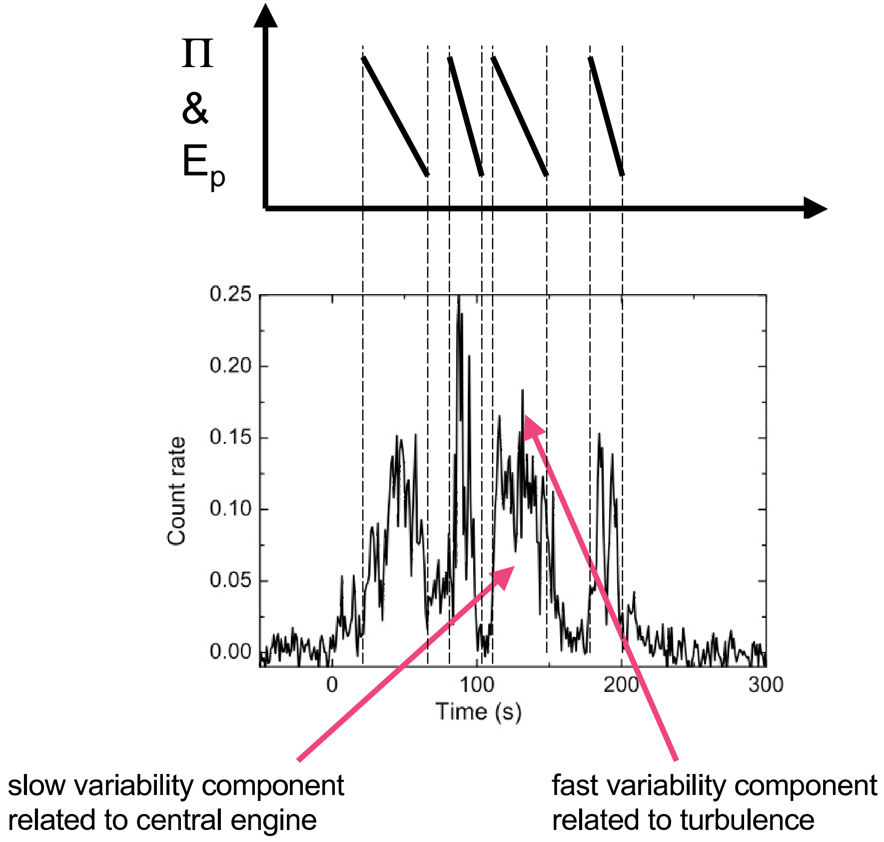
- The variability in this model has no direct connection with the central engine activity, while the evidence of an engine-related variability (e.g., those in X-ray flares) is mounting.

Models in the MHD regime (Thompson 1994; Spruit et al. 2001; Drenkhahn & Spruit 2002; Vlahakis & Konigl 2003; Giannios 2008; Komissarov et al. 2009).

- These models invoke magnetic dissipation at smaller radii to enhance the photosphere emission. At large radii, the outflow is no longer PFD, so that the IS model can still operate.

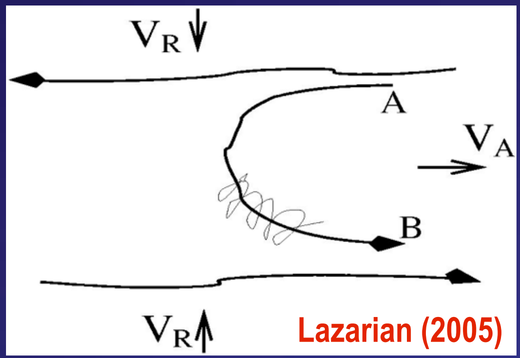
- The main difference between the ICMART model and other MHD models is whether the magnetic energy is released abruptly at a large radius or continuously at small radii.

Variabilities are naturally explained

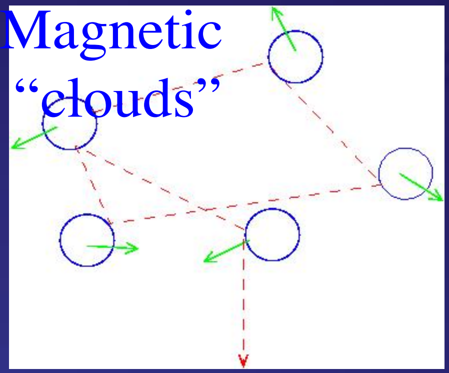


Open question: Acceleration vs. heating

- Kinetic energy vs. ohmic heating
- 1st order vs. 2nd order acceleration



de Gouveia Dalpino & Lazarian (2005)



- Bulk heating vs acceleration of MW tail particles

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  During fast reconnection, outflow kinetic energy > heating

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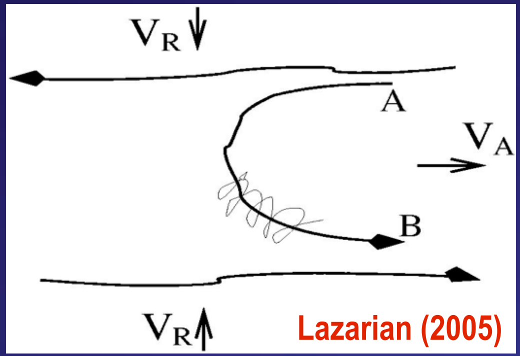

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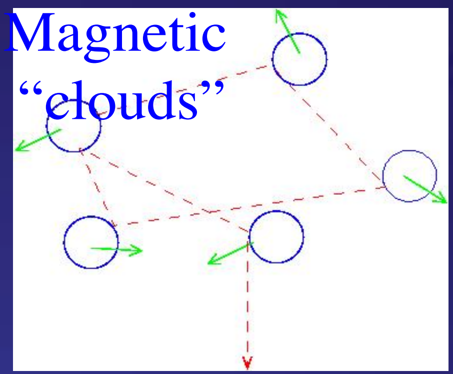

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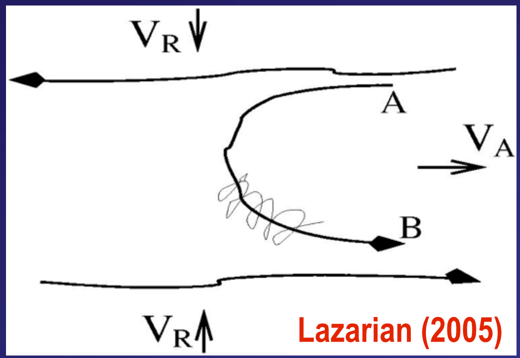

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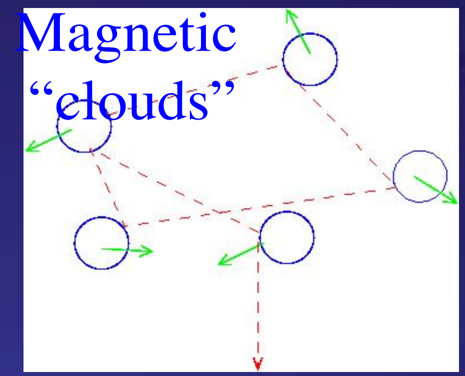


- Bulk heating vs acceleration of MW tail particles

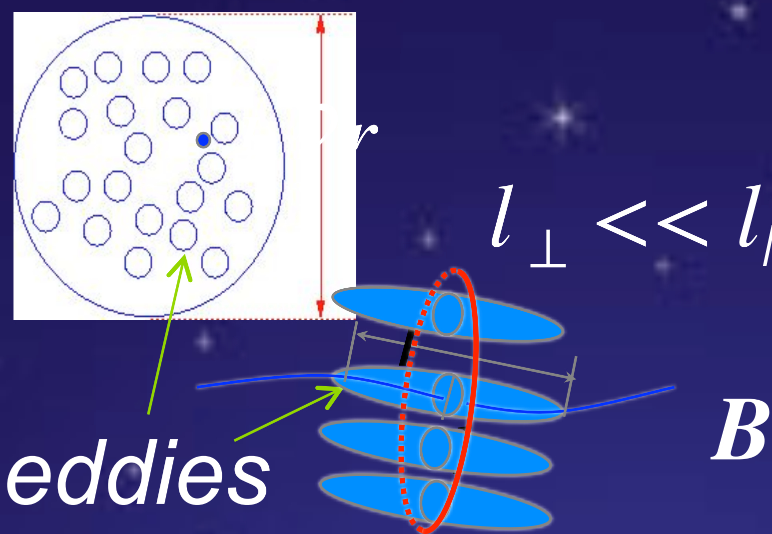
  Nonthermal damping is found less than 10% of thermal damping during the transit time acceleration by fast modes (Petrosian, Yan & Lazarian 2006).

TURBULENCE ACCELERATION MODEL

- Turbulence is naturally generated during shell shell collisions and reconnection process
- Turbulence energy is cascaded down to small scales through weakly coupled fast modes and Alfven modes
- Energy in both channels can be transferred to particles
- The acceleration efficiency is much enhanced in relativistic turbulence since the electric fluctuations are $\delta E \sim \beta_A \delta B$ larger than the magnetic ones

Channel 1: through Alfven cascade

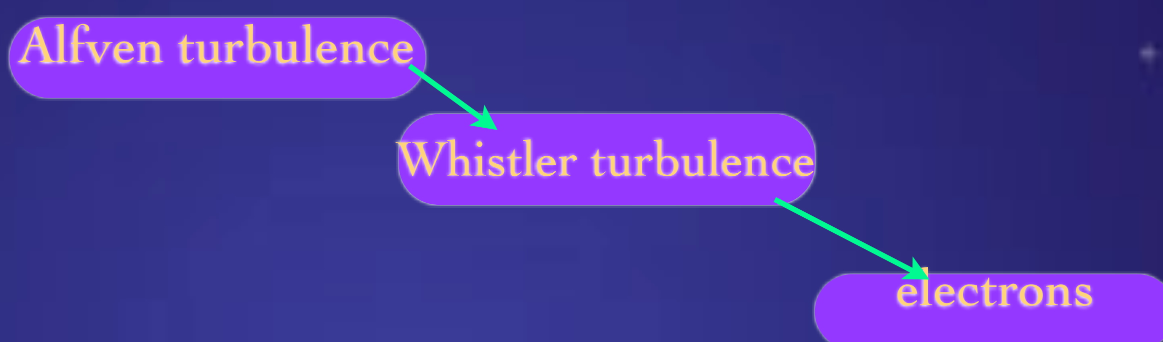
Alfven modes



$$l_{\perp} << l_{||} r_L$$

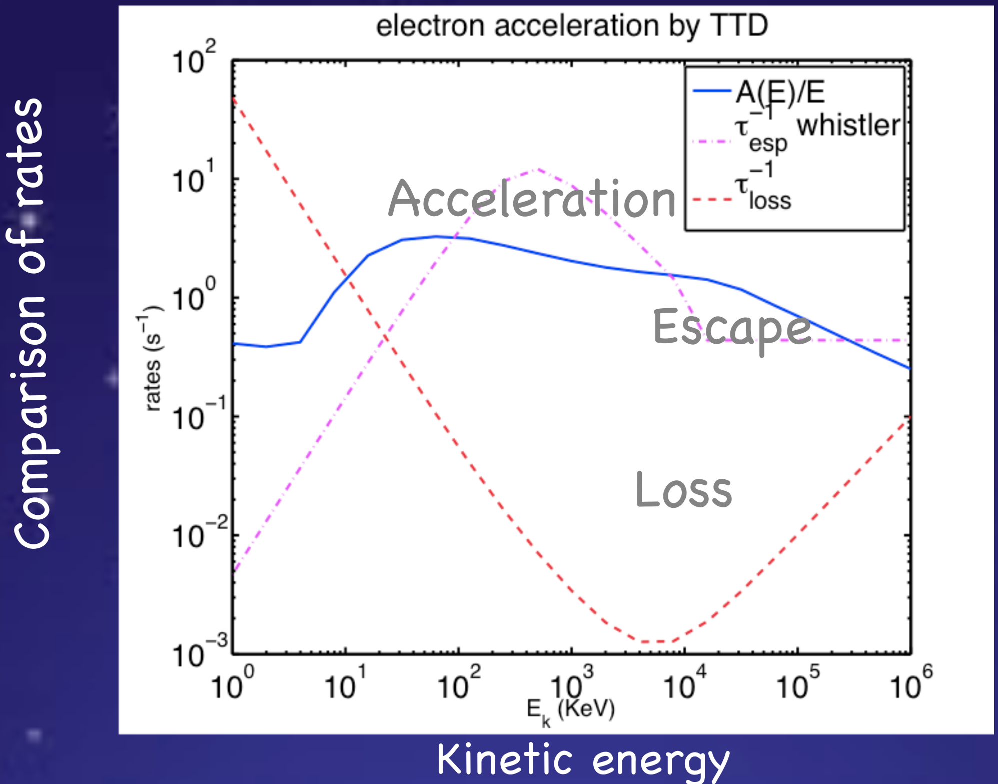
<u>*Resonant Interaction is substantially reduced !*</u>

(Yan & Lazarian 02, 04, 08)



Channel 2: through both fast modes cascade!

Fast modes



TTD Acceleration by fast modes is an important mechanism to generate energetic electrons (Lazarian et al. 2003, Yan, Lazarian & Petrosian 2008).

Summary

- Traditional fireball model faces big problems.
- Recent understandings of MHD turbulence and reconnection shed lights on GRB physics.
- Highly magnetized GRBs are dominated by nonthermal emission released during the fast reconnection events.
- The central engine is intermittent, launching an unsteady wind. The shells interact via collisions, which distort the field lines, making the field more and more turbulent.
- At a certain large radius, turbulence is sufficient to trigger a fast reconnection, corresponding to a GRB pulse.
- Further modeling of both acceleration by reconnection and turbulence is necessary to make quantitative predictions on issues like acceleration vs. heating.