Astroparticle theory

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On behalf of THAT group

DESY Zeuthen & Uni Potsdam

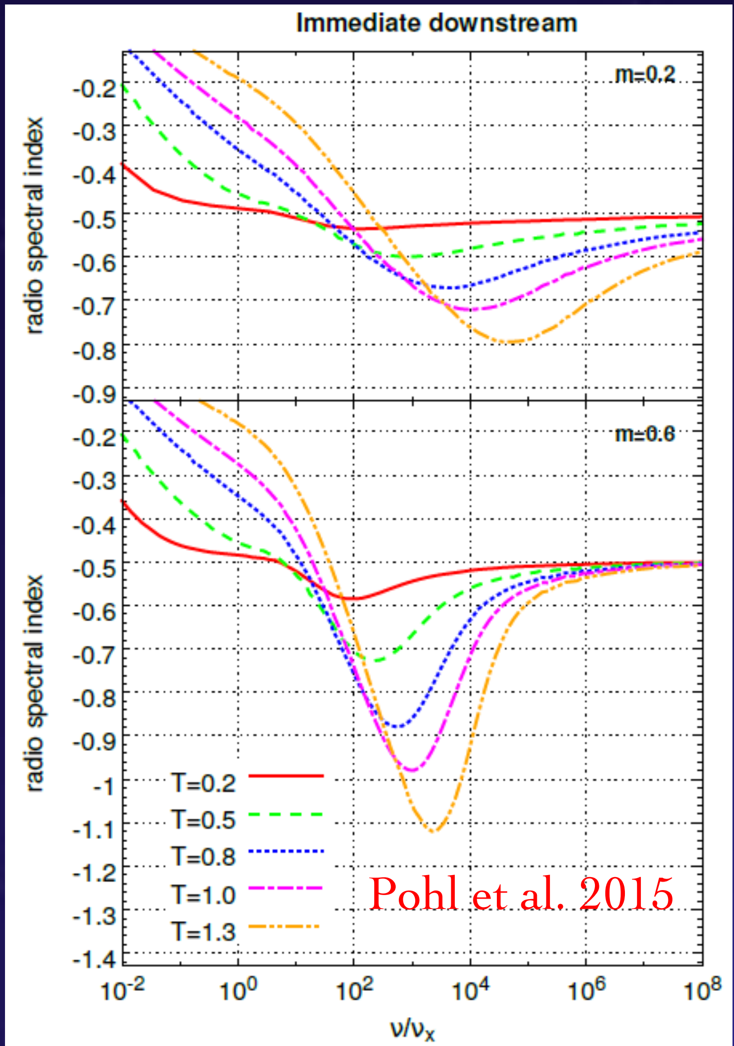
Science topics

- Origin of Cosmic rays
- Particle acceleration and propagation
- Underling plasma processes
- Ultra high energy cosmic rays: GRBs, AGNs, etc
- Neutrino Physics

Scientific highlights from existing group members:

- Reacceleration of electrons in supernova remnants (led by M. Pohl)
- Cosmic-ray anisotropy *ex nihilo* (led by M. Pohl)
- Neutrino emission from GRBs (led by W. Winter)

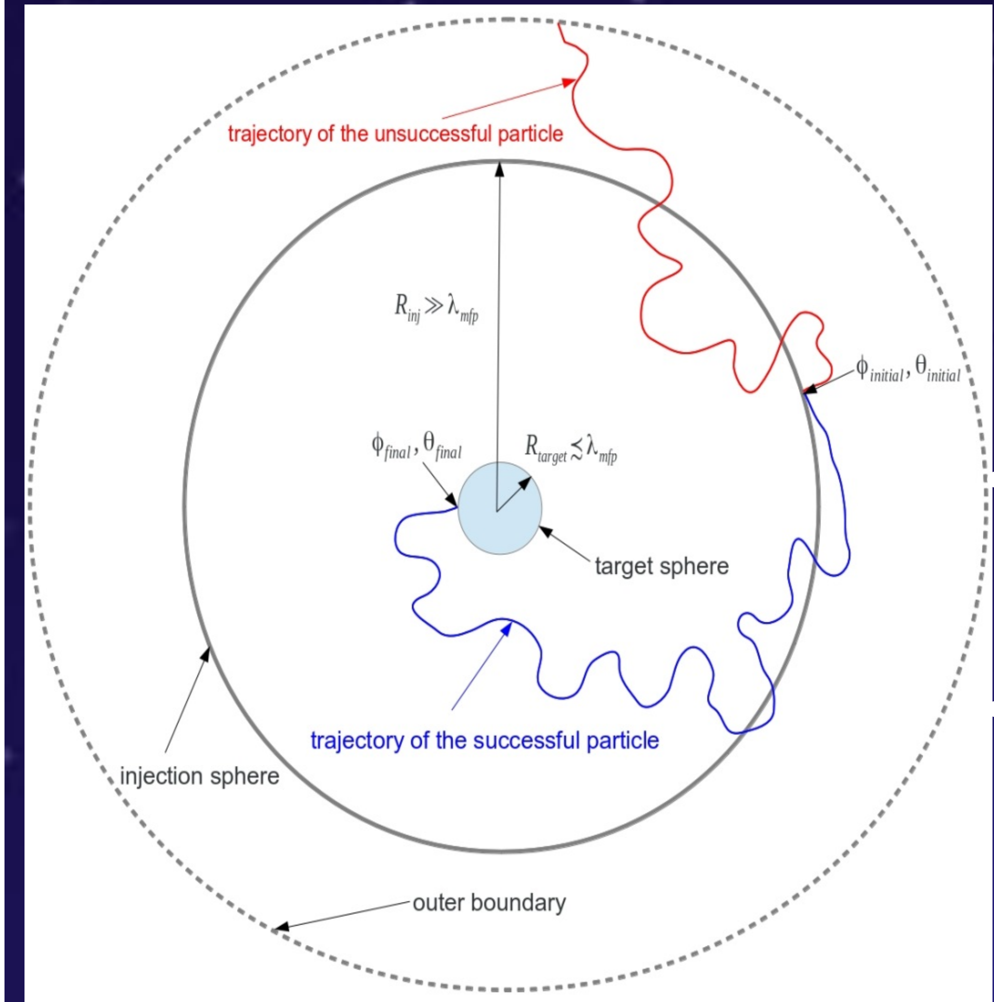
Reacceleration of electrons in SNRs



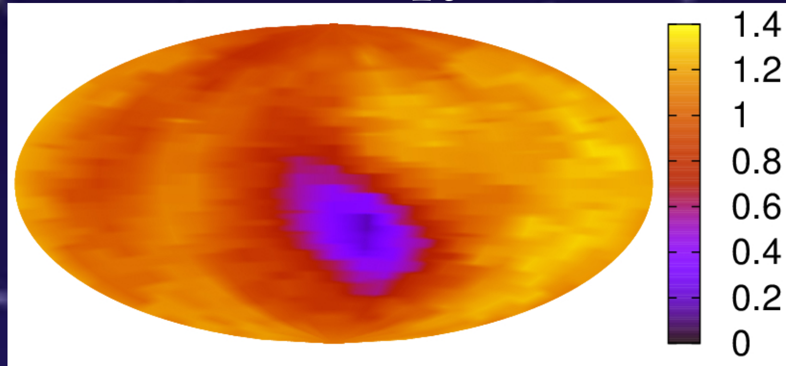
Reacceleration

- can happen virtually everywhere
- is usually slow, but can be effective in some environments, e.g., SNRs
- Natural explanation of soft radio spectra

Cosmic-ray anisotropy



Anisotropy

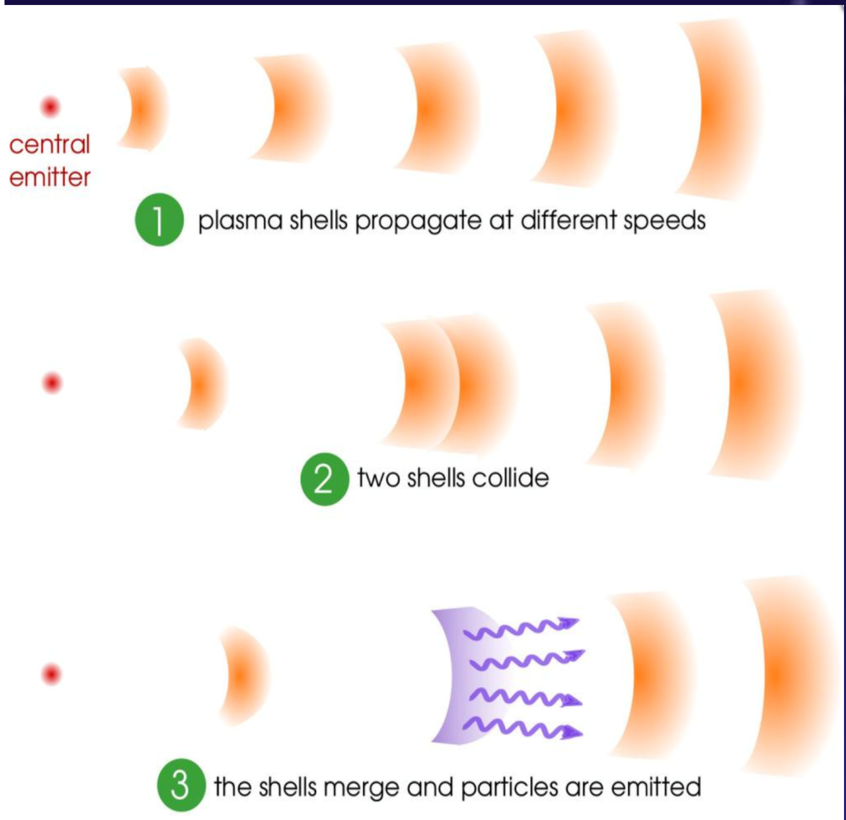


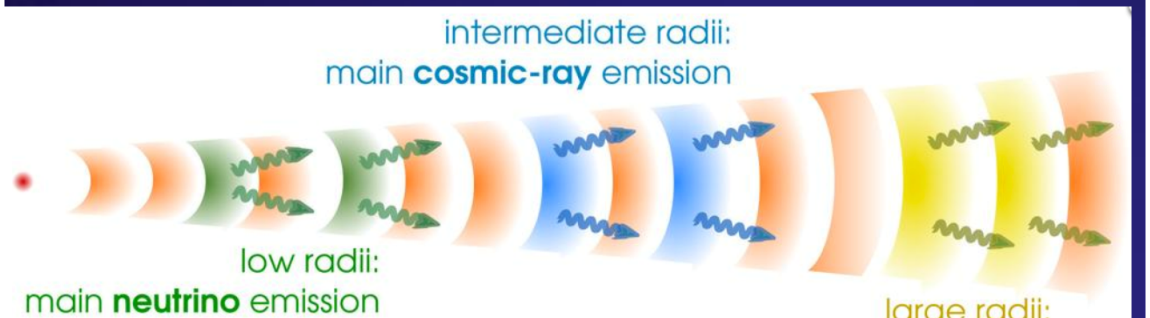
- Anisotropy is created *ex nihilo*, no initial dipole is needed
- Complicated patterns that do not strongly depend on λ_{mfp} / λ_{max}
- Little, if any, correlation with magnetic field orientation

Rettig & Pohl 2015 PRL submmited

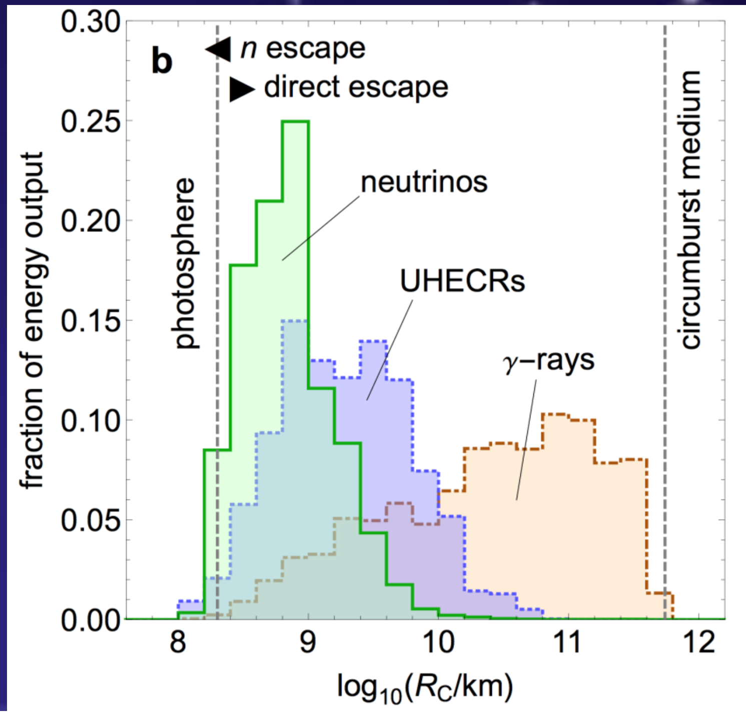
Multiple zone model for GRBs

- The different messengers originate from different regimes of the GRB
- Interesting implications for gamma ray-neutrino connection and expected “minimal” neutrino flux





Bustamante et al. 2015



Some new perspectives I bring in

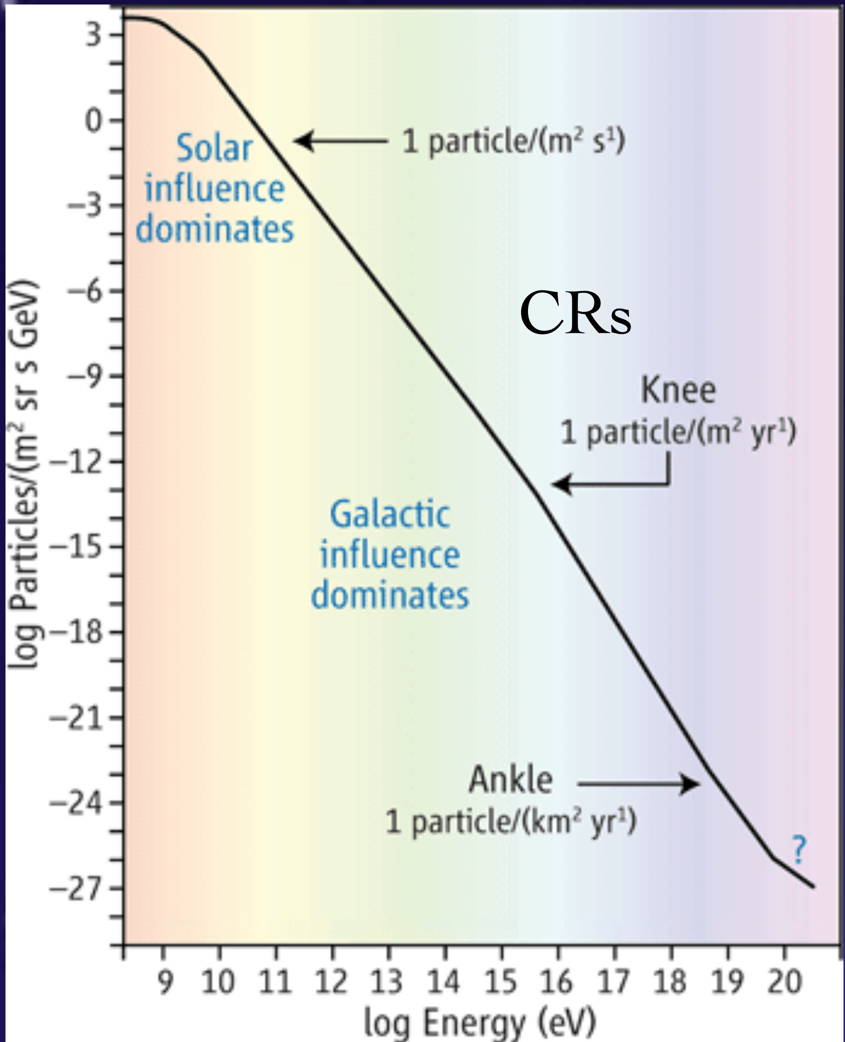
a. Particle Scattering in tested model of turbulence

b. Cross field transport in turbulence

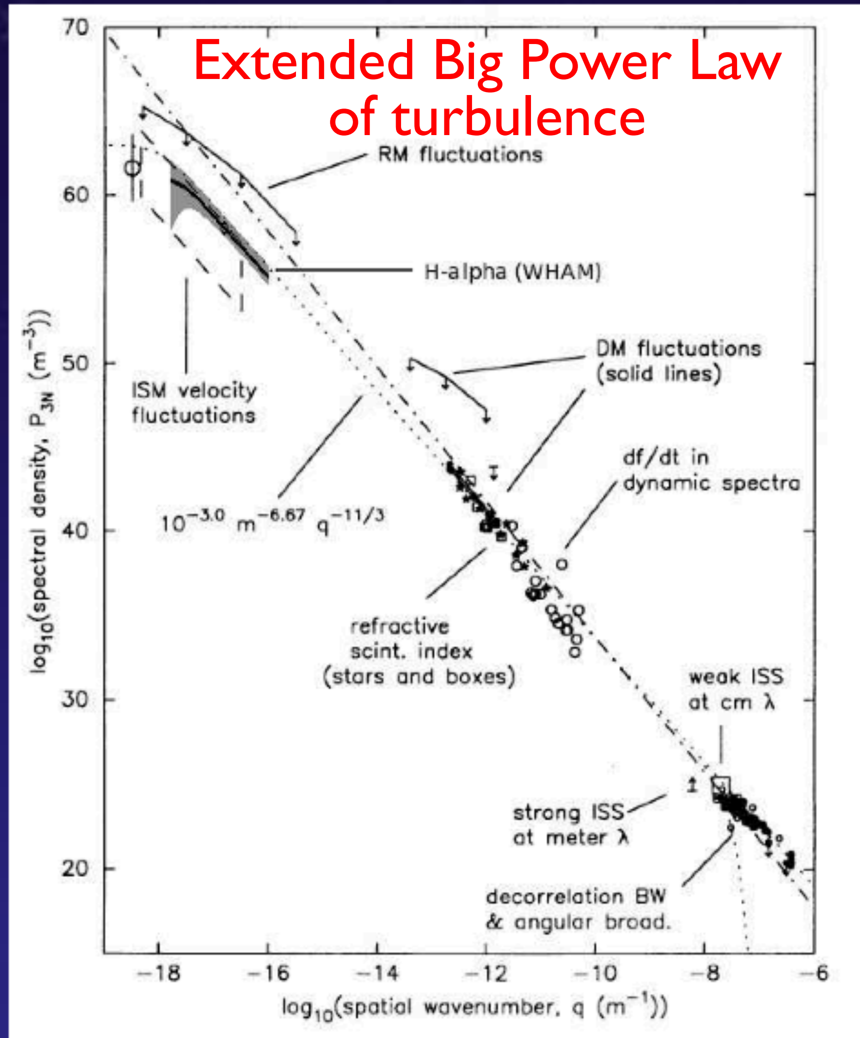
c. Turbulent reconnection model of ϒ ray burst (GRBs)

d. CR transport in partially ionized media

Cosmic Rays and turbulence

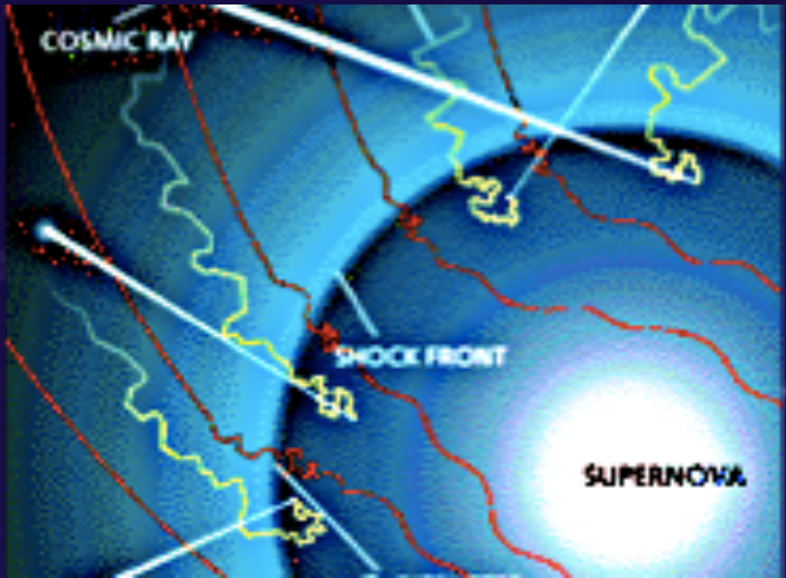


M. Duldig 2006

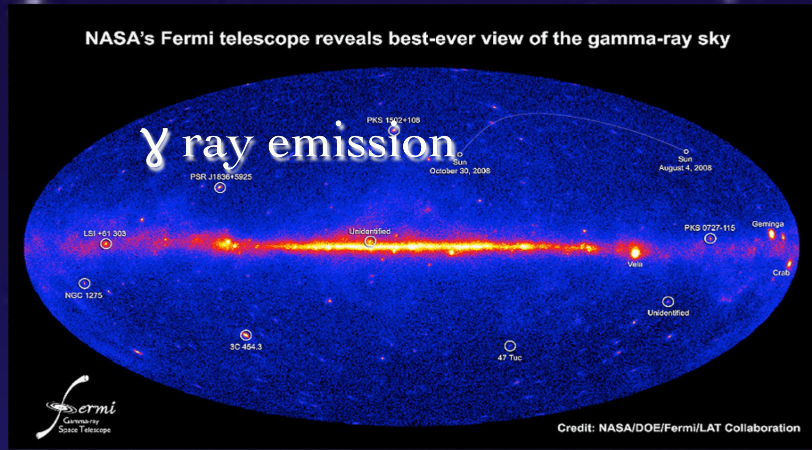


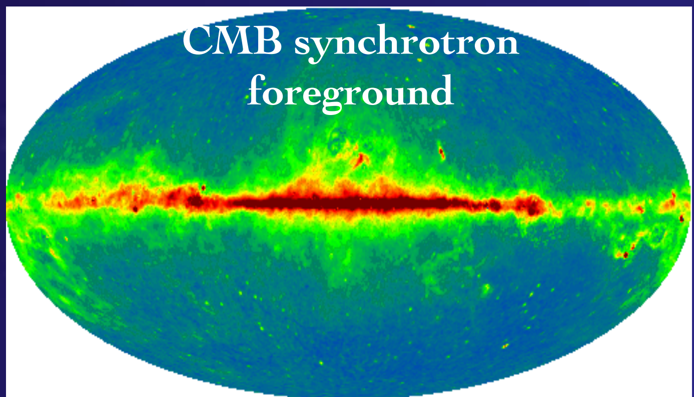
Armstrong et al. 1995, Chepurnov & Lazarian 2009

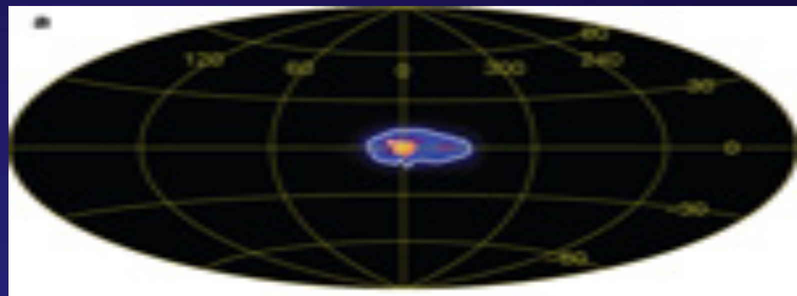
Importance I: Cosmic Ray (CR) Propagation



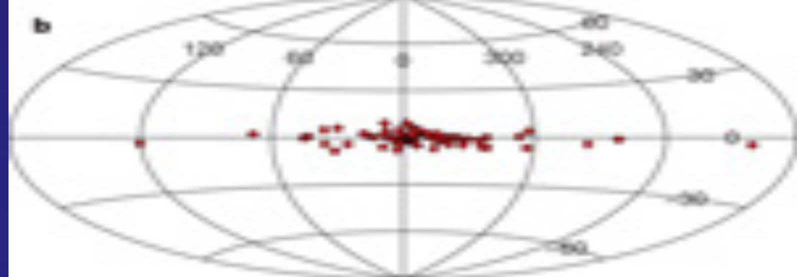
— Particle trajectory
— Magnetic field





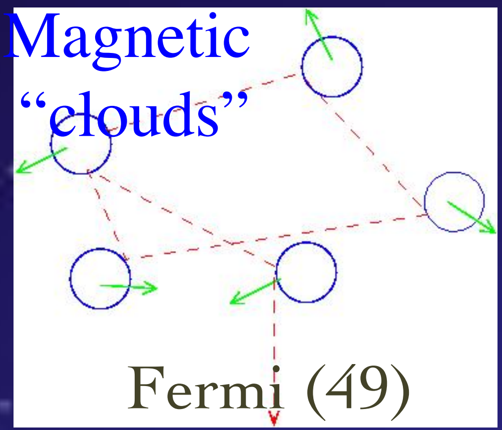


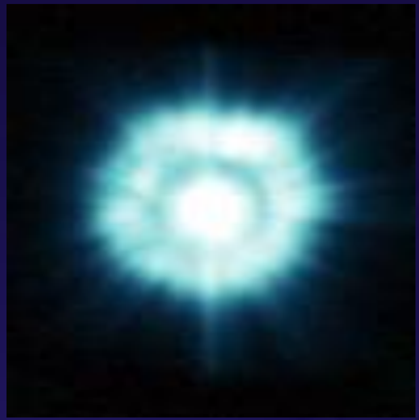
Diffuse Galactic 511 keV radiation



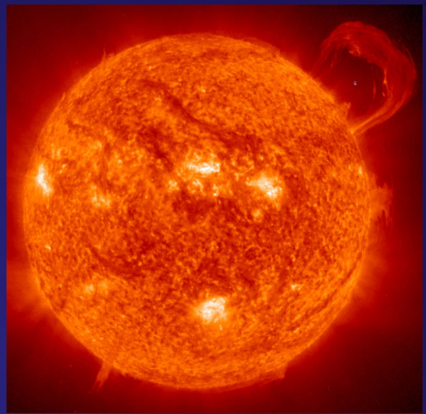
Importance of wave-particle interaction: Fermi II

Stochastic Acceleration:





Gamma ray burst



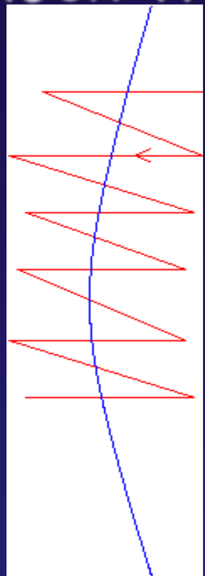
Solar Flare

Importance to Fermi I acceleration

- Shock Acceleration

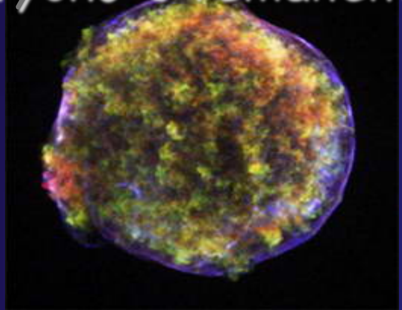
Shock front

Turbulence generated by streaming

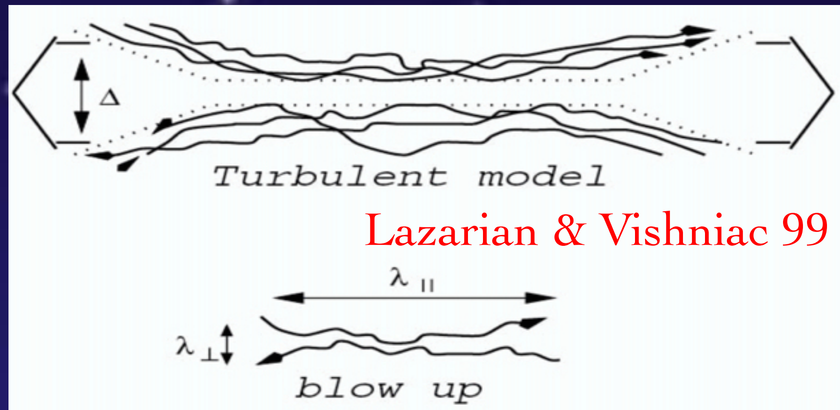


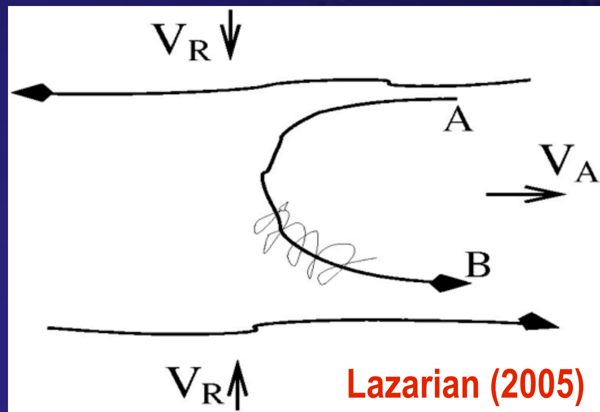
Turbulence generated by shock

Tycho's remenant



- Reconnection Acceleration





Some new perspectives I bring in

a. Particle Scattering in tested model of turbulence

b. Cross field transport in turbulence

c. Turbulent reconnection model of Υ ray burst (GRBs)

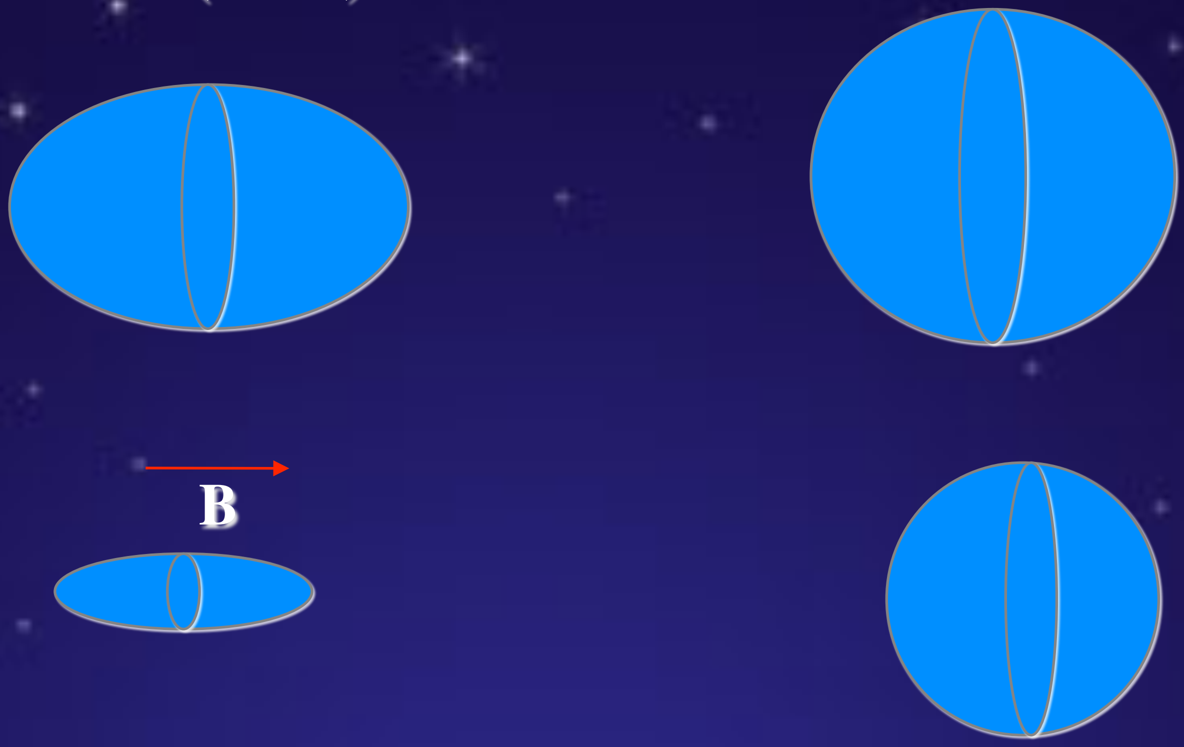
d. CR transport in partially ionized media

Credit: Francesca Grifo

Tested model of MHD turbulence

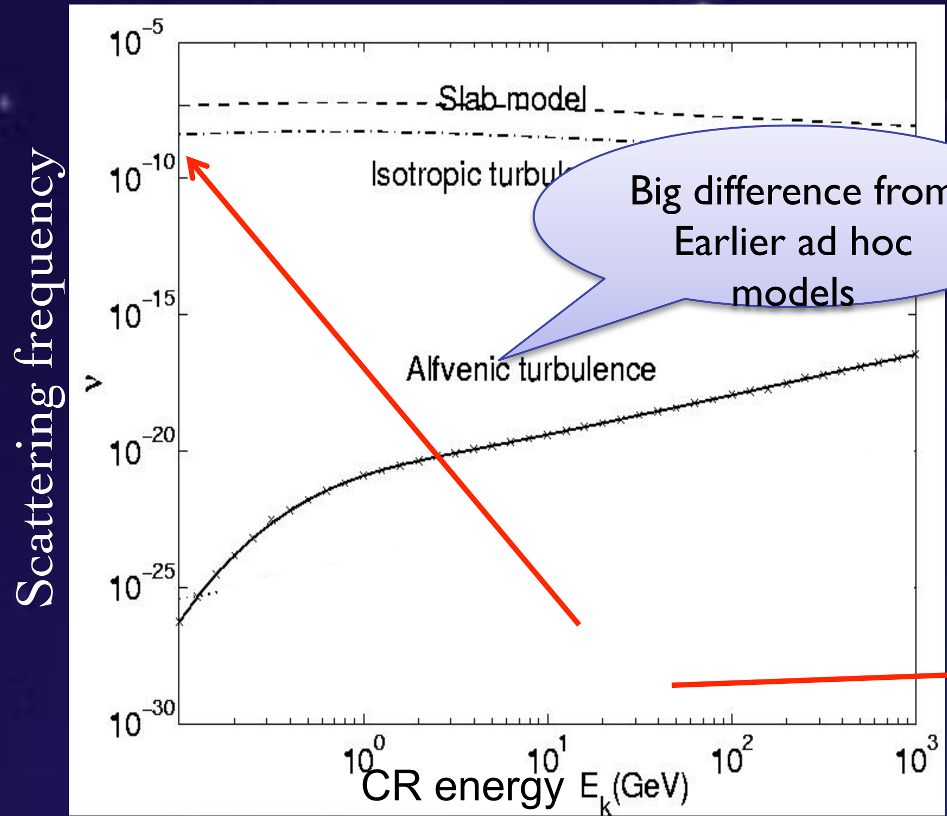
Alfven and slow modes (GS95)

fast modes

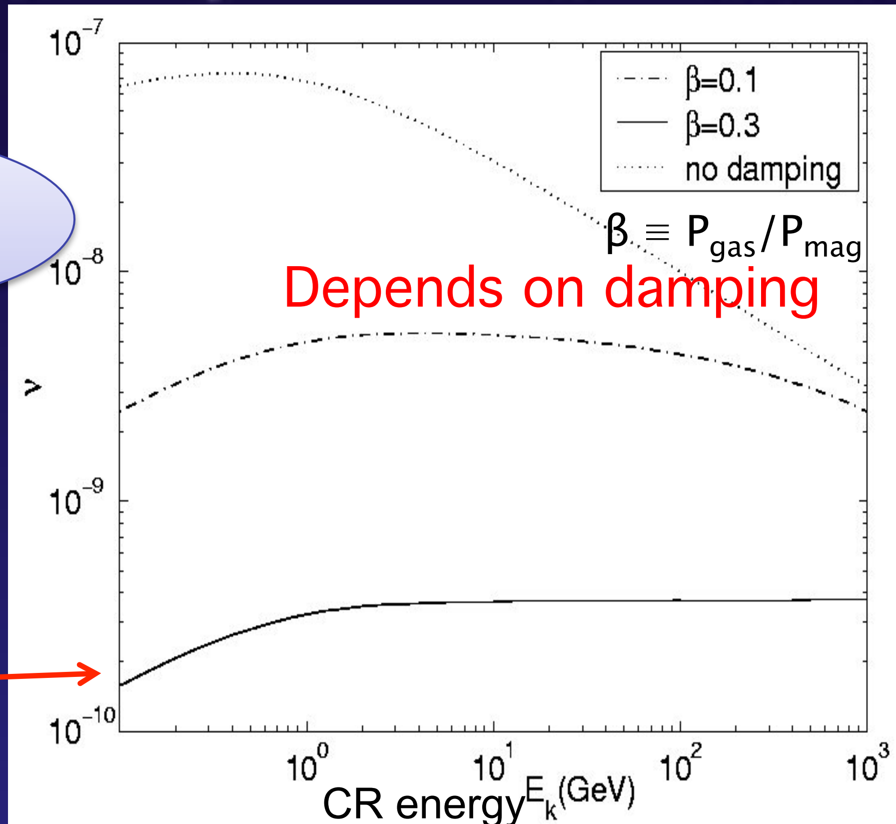


Fast modes dominate CR scattering!

Alfven modes

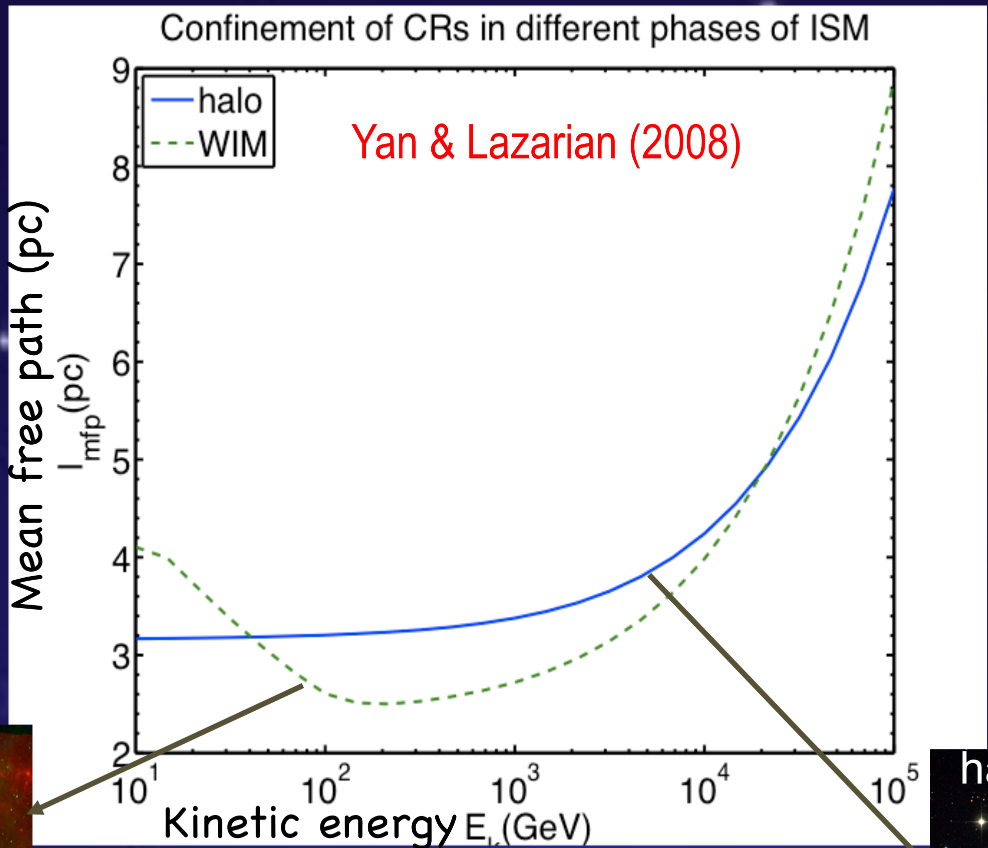


Fast modes



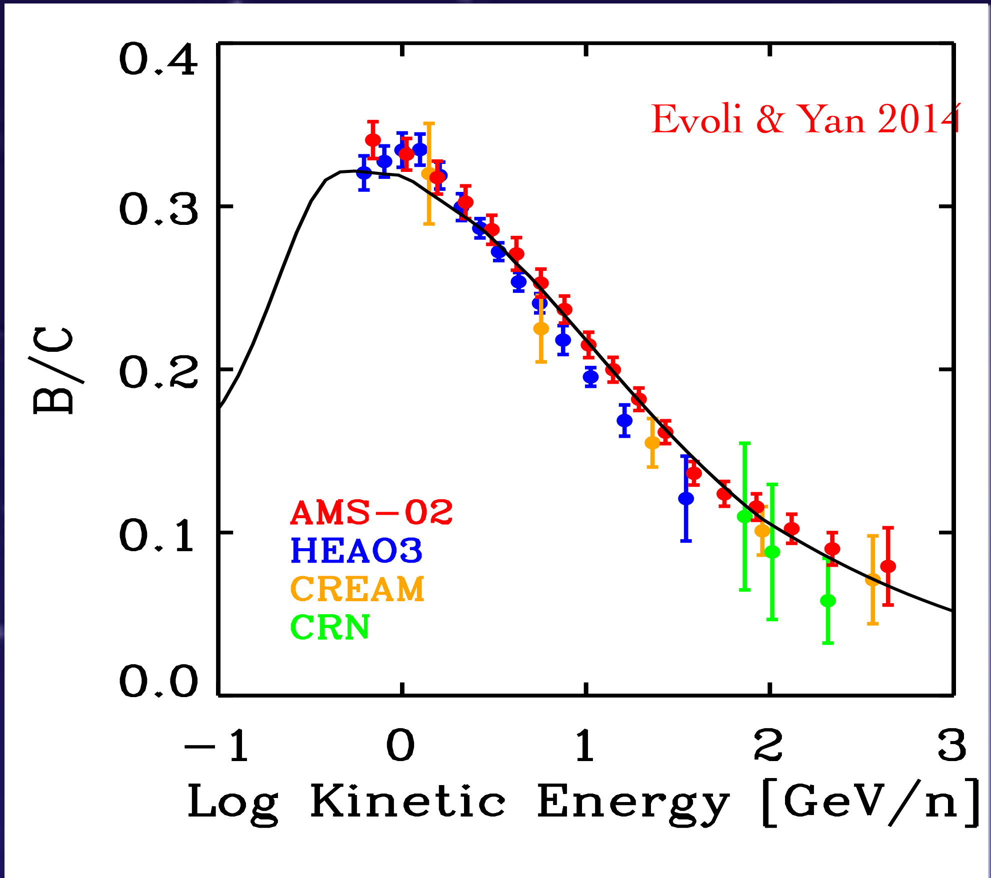
Anisotropy (Elongated eddies along the B field) makes orders of magnitude difference (Yan & Lazarian 02, 04)! Confirmed later by both Nonlinear theory (YL08) and numerical test (Xu & Yan 2013).

Major Implication: CR Transport varies from place to place!



Observational support on nonuniform propagation of CRs (AMS 2010; Fermi-LAT 2011,2012; PAMELA 2011):

Implications

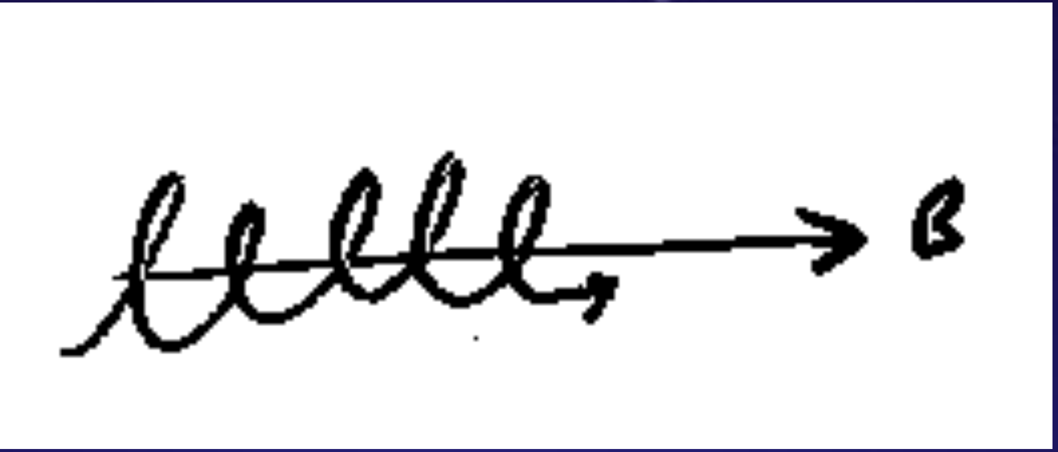


1 GeV peak of B/C ratio can be produced without introducing the reacceleration!

To be studied:

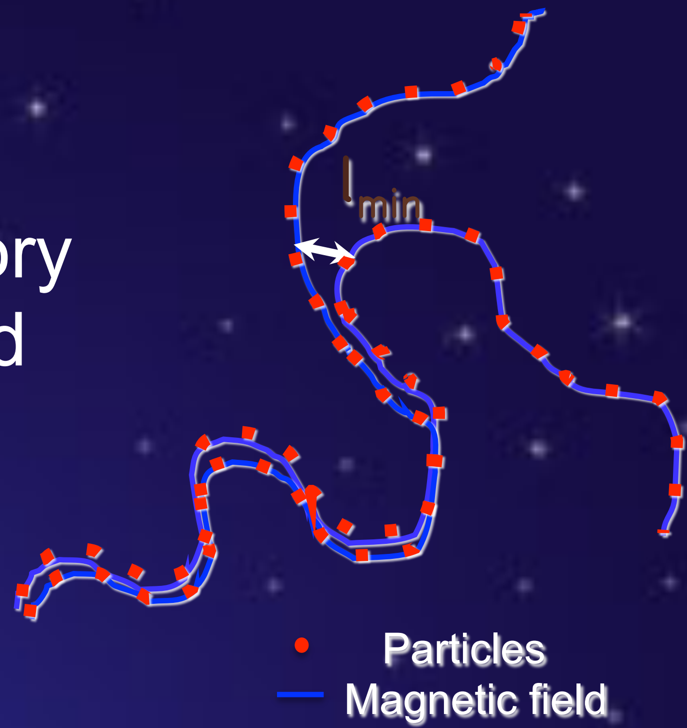
- Cosmic ray spectrum; Secondary elements; Low energy positron excess; Anisotropic distribution; Diffuse γ ray emission
- Positron excess and dark matter: an illusion from current CR propagation modeling?

b) Cross field transport



Cross field transport is not small!

- In turbulence, particles' trajectory become independent when field lines are separated by the smallest eddy size, l_{min}.



Cross field transport is normal diffusion on large scales

Theoretical prediction:

$M_A \equiv \delta B/B$

Yan & Lazarian 2008

Numerical simulation:

the best fit

$$\boxed{D_\perp \propto M_A^{3.9}}$$

Xu & Yan 2013

Superdiffusion (SD) on small scales

- Theoretical prediction

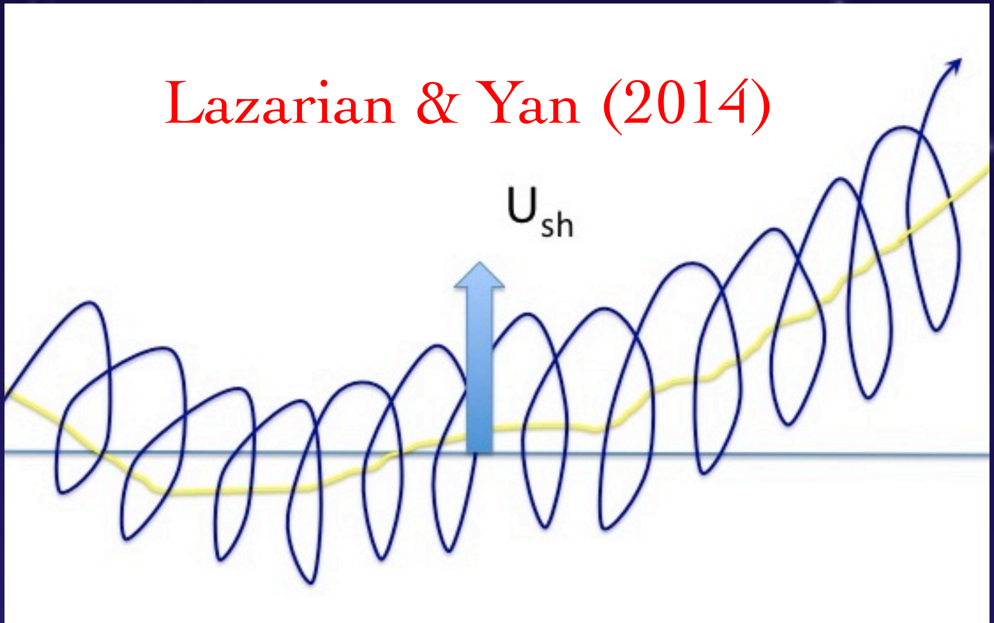
Yan & Lazarian 2008

- Numerical result

Xu & Yan 2013

$$\boxed{\frac{\langle(\delta z)^2\rangle}{|\delta x|^3} \propto M_A^{3.9}}$$

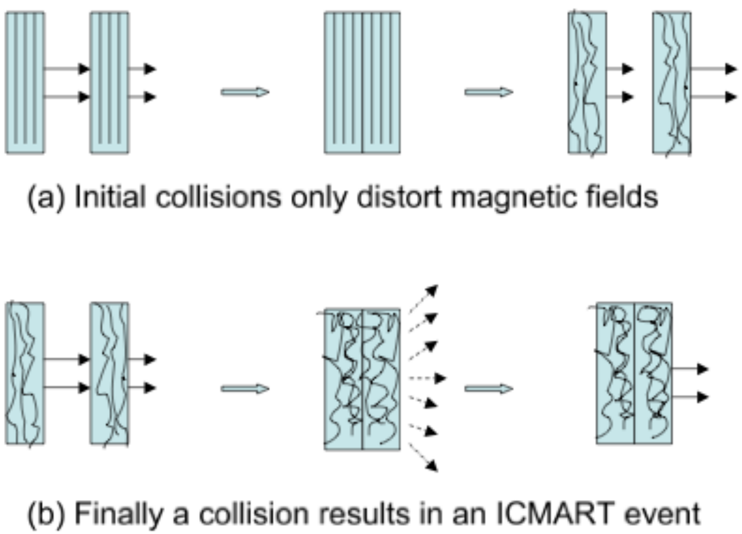
Implication: shock acceleration is independent of B field direction

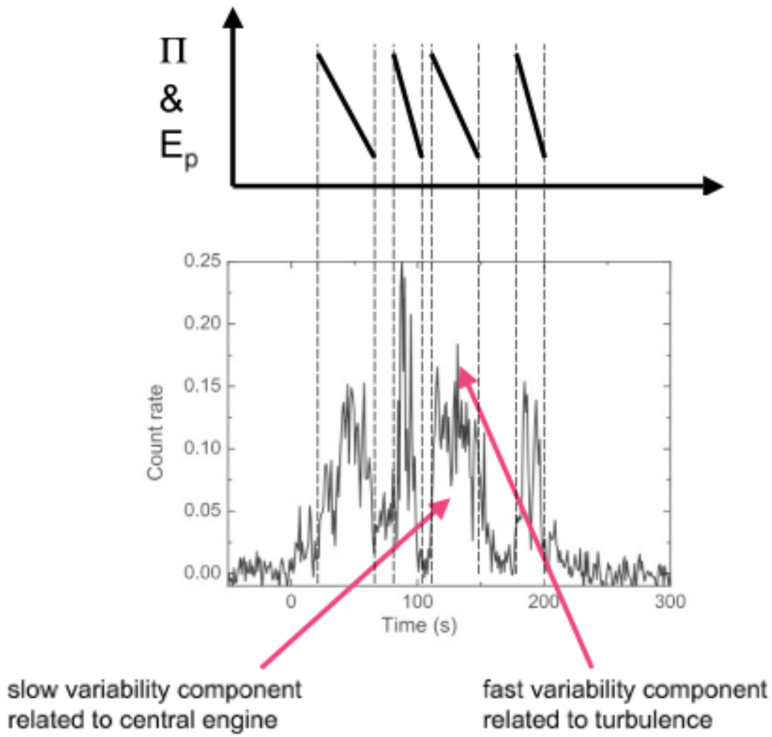


To be further studied:

Shock Acceleration in the presence of super-diffusion.

C)ICMART MODEL FOR GAMMA RAY BURST



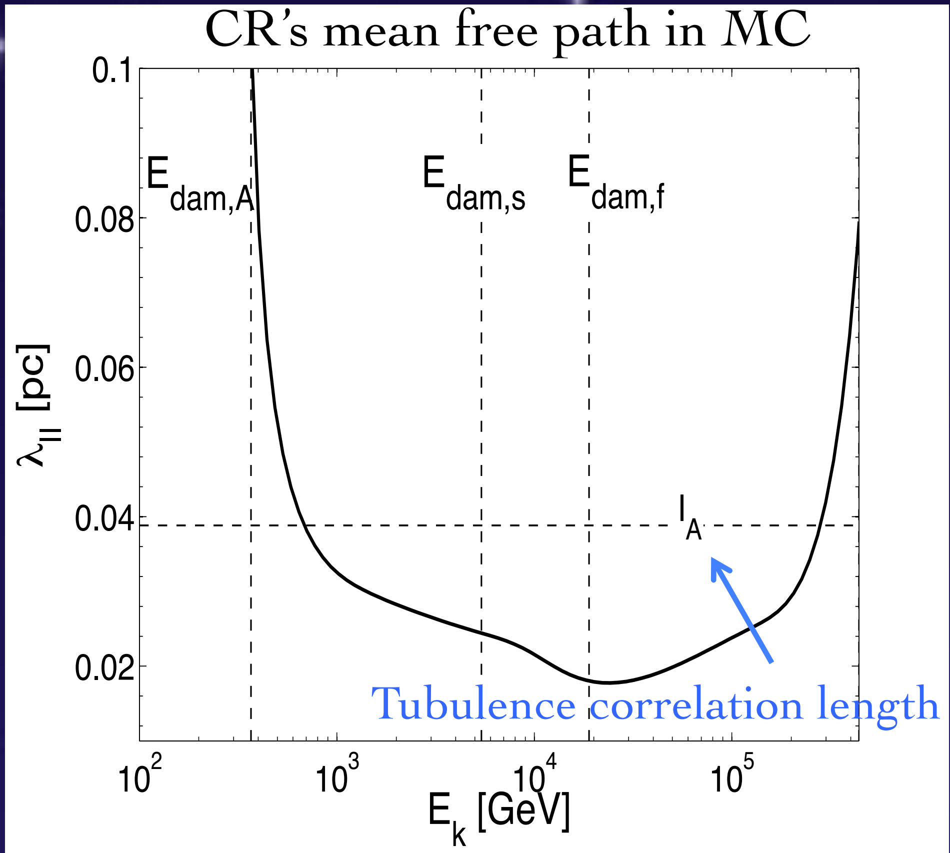


Zhang & Yan (2011)

Internal collision induced turbulence reconnection model provides a natural explanation for highly magnetized GRBs (~ 50 citations in 9 months)

Note: we first proposed this idea in Lazarian et al. (2003).

D) Propagation in partially ionized medium



To be studied:

- γ ray emission from molecular clouds
- Ionization in clouds

Xu et al. 2015 ApJ submitted

Summary

- MHD turbulence is a key player for particle transport and acceleration.
- Compressible fast modes dominates CR transport through direct scattering. CR transport therefore varies from place to place.
- CR perpendicular transport is diffusive in large scale turbulence and superdiffusive (SD) on small scales.

Some future perspectives:

- Existing codes (GalProp, Dragon, etc) are to be modified to account for these new understandings.
- In the presence of turbulence, shock acceleration is insensitive to B field direction. The acceleration with SD is to be studied.
- Reconnection Acceleration in relativistic turbulence is important channel for ultrahigh energy CRs and will be studied.
- CR transport and gamma ray emission from molecular clouds.