# The influence of turbulence on the transport of energetic particles[1]

M. Hussein[I], R. C. Tautz[II], & A. Shalchi[I]

[I]Department of Physics and Astronomy - University of Manitoba - Winnipeg - Manitoba - Canada

[II]Zentrum Für Astronomie and Astrophysik - Technische Universität Berlin - Berlin - Germany

ICRC
The Astroparticle Physics Conference
34th International Cosmic Ray Conference
July 30 - August 6, 2015
The Hague, The Netherlands

**Supported by:**

University of Manitoba · WestGrid · NSERC

## ABSTRACT

We explore the influence of turbulence on the transport of energetic particles using test-particle simulations. We compute diffusion coefficients, $\kappa_{ii}$, or equivalently mean free paths (MFP), $\lambda_{ii}$, for five widely used turbulence models. We show that these coefficients have similar rigidity dependence regardless of the used turbulence, thus we conclude that this influence is not as strong as originally thought.

## Introduction

Turbulence appears in almost all areas of nature. In space, turbulence is a generic feature in astrophysical plasmas. Solar wind and interstellar medium are among a wide variety of astrophysical plasmas that are magnetized and turbulent[2]. When energetic particles interact with turbulent magnetic fields they scatter parallel and perpendicular to the background field in a diffusive fashion described by diffusion coefficients, $\kappa_{\parallel}$ and $\kappa_{\perp}$.

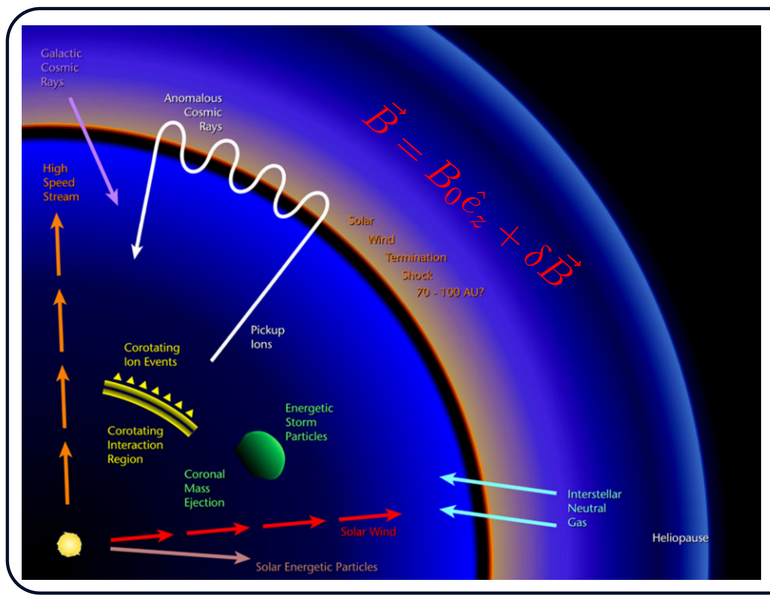



**Fig 1: schematic diagram showing different key energetic particle populations with potential magnetized objects in the heliosphere (Mewaldt et al. 2000)**

## Energetic Charged Particles (ECPs)

ECPs are low density, collisionless, and incompressible charged system where particles are treated separately. They behave fundamentally different than the bulk of the plasma when interacting with magnetized bodies. Examples are cosmic rays (CR)[2], solar energetic particles (SEPs), and runaway electrons in Tokamaks.

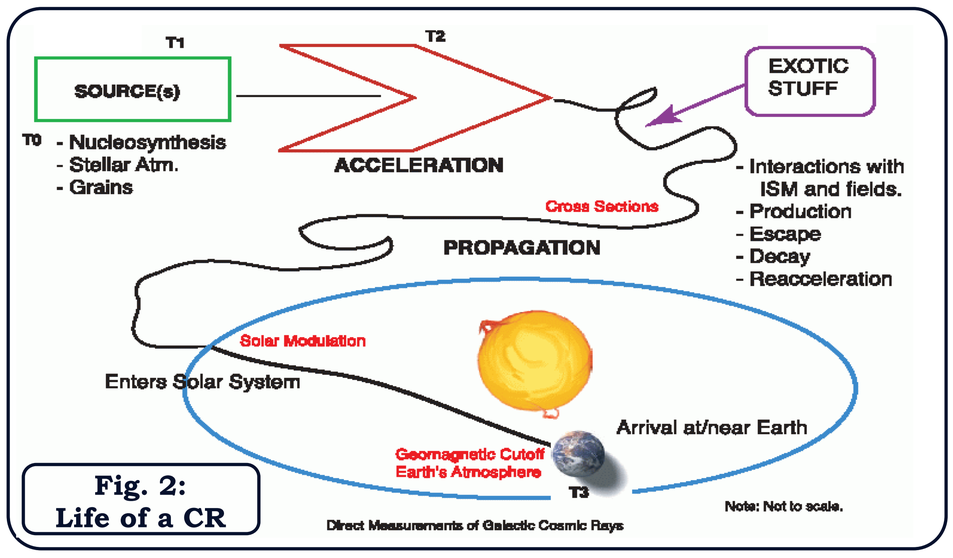



**Fig. 2: Life of a CR**

## Methodology

Tracking ECPs diffusion in realistic turbulence is our aim. In test-particle simulations and in analytical diffusion theories, an important quantity is the magnetic correlation tensor in wavenumber space defined as:

$$P_{lm}(\vec{k}) = \langle \delta B_l(\vec{k}) \delta B_m^*(\vec{k}) \rangle.$$

The form of the tensor is still unclear and differ from one physical scenario to the other. We focus on five different turbulence models which are generally accepted. Below we show there geometries.

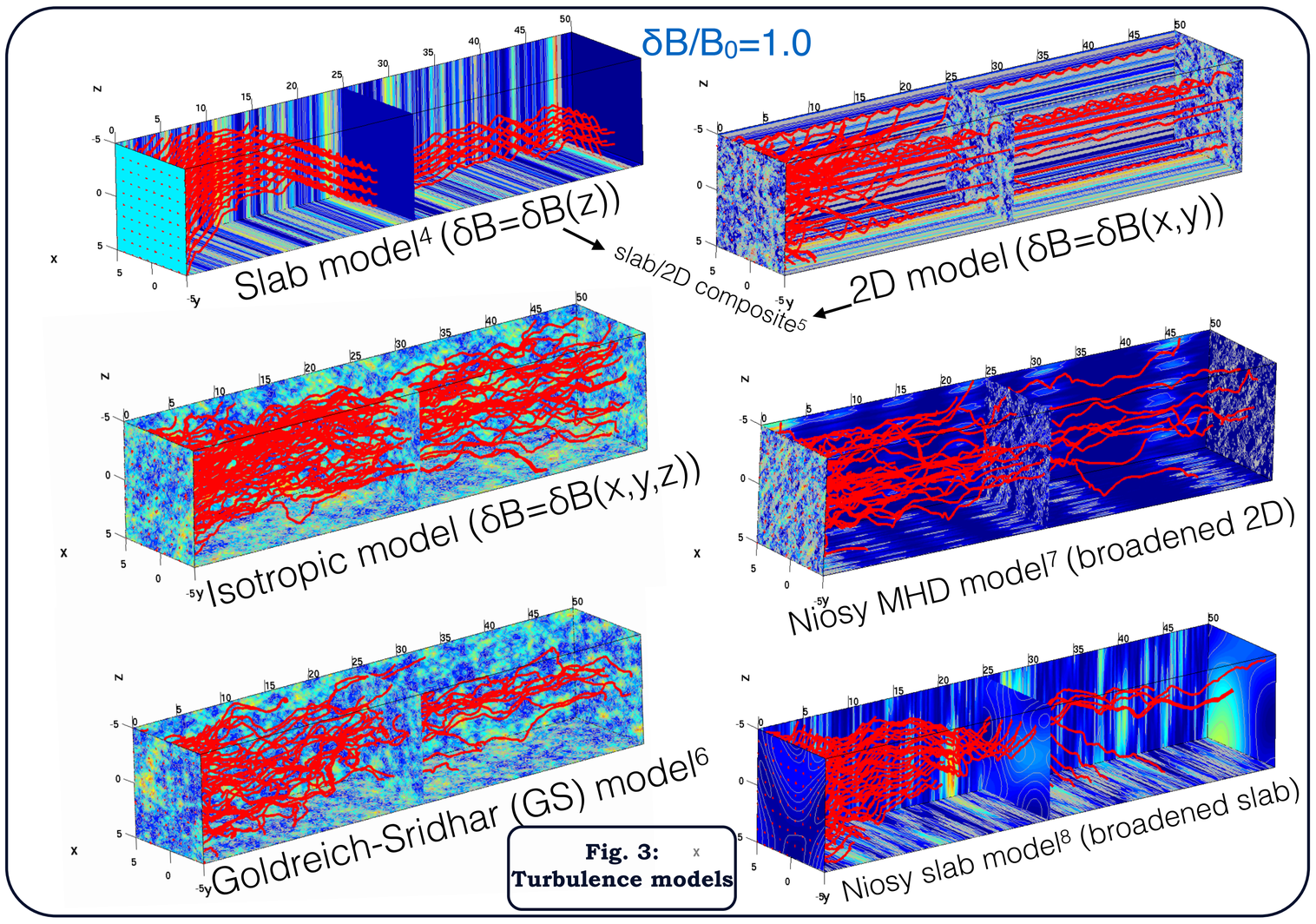
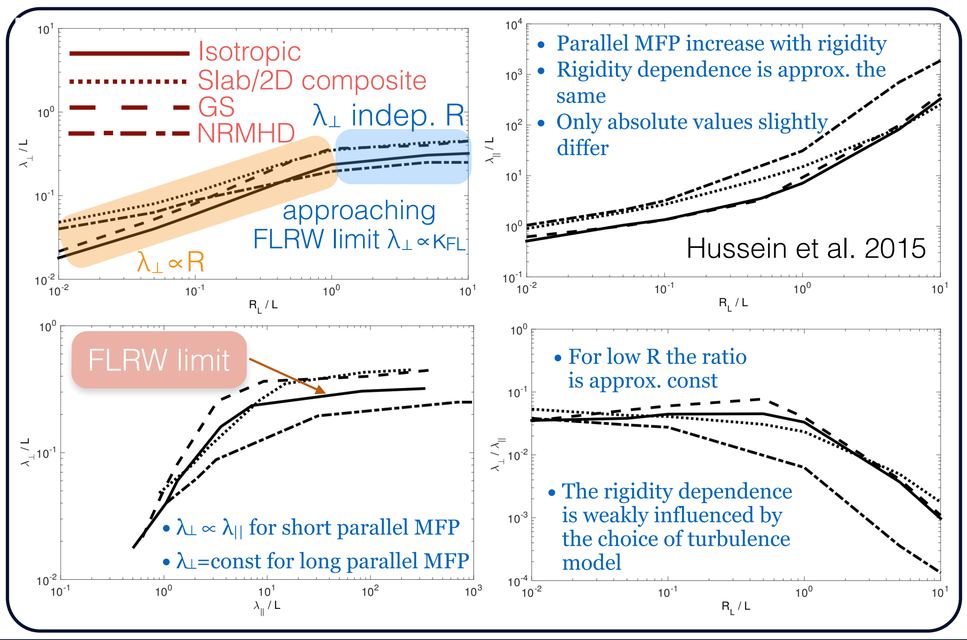



**Fig. 3: Turbulence models**




## Results

- Diffusion coefficients have a similar rigidity dependence
- Perpendicular diffusion coefficient is directly proportional to the parallel coefficient for small rigidities
- Perpendicular diffusion is rigidity independent for higher rigidities and tends toward FLRW limit
- Recent analytical findings predict that only fundamental properties of turbulence (Kubo number) and parallel MFP control the perpendicular diffusion[9]

References
[1] Hussein, M. et al. (2015), J. Geophys. Res.: Space Phys, 120, 4094-4111
[2] Rudiger, G and Hollerbach, R, 2004, The Magnetic Universe (Weinheim: Wiley-VCH)
[3] Schlickeiser. R, 2002, Cosmic Ray Astrophysics (Berlin: Springer)
[4] Jokipii, J. R. (1966), Cosmic-Ray Propagation. I., Astrophys. J., 146, 480
[5] Bieber, J. W. et al. (1994), Proton and electron mean free paths, Astrophys. J., 420, 294
[6] Goldreich, P., and S. Sridhar (1995), Astrophys. J., 438, 763
[7] Ruffolo, D., and W. H. Matthaeus (2013), Physics of Plasmas, 20, 012308
[8] Shalchi, A. (2015), Physics of Plasmas, 22, 010704
[9] Shalchi, A. (2014), Advances in space Research, 53, 1024

husseinm@myumanitoba.ca