Simulations of energetic particles interacting with dynamical turbulence

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ABSTRACT

Using test-particle simulations we investigate the transport of energetic particles in the interplanetary space. We employ for the first time dynamical turbulence with the so-called damping model to calculate parallel and perpendicular diffusion coefficients or equivalently mean free paths (MFP), $\lambda_\parallel$ & $\lambda_\perp$, and compare them with solar wind observations. It is shown that a very good agreement can be established between our simulations and the Palmer consensus range.

Introduction

A longstanding problem in space science is the motion of energetic particles such as cosmic rays through the solar system (Fig.1). Palmer (1982) used observational data and was able to represent parallel diffusion by a band known as *Palmer consensus range*. He also compared his results with quasilinear coefficients and find no agreement. Hence our understanding need to be modified.

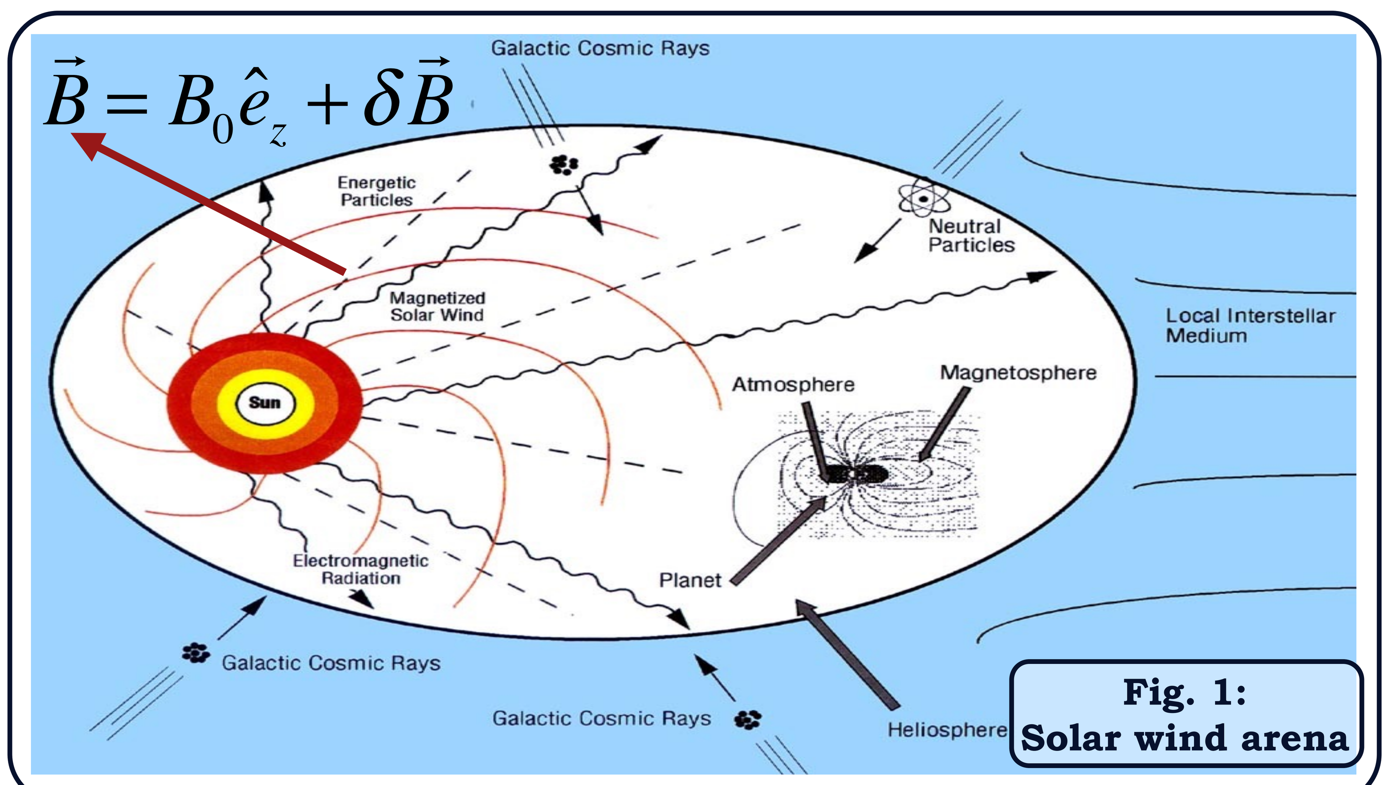


Fig. 1: Solar wind arena

Bieber et al. (1994) extended the quasilinear approach by performing three steps. First they modified the turbulence model by using the so-called two-component rather than the slab model. Second, they added dissipation effects to the employed spectrum. Finally, the magneto-static model was replaced by a dynamical turbulence. An agreement with the *Palmer consensus range* was reached.

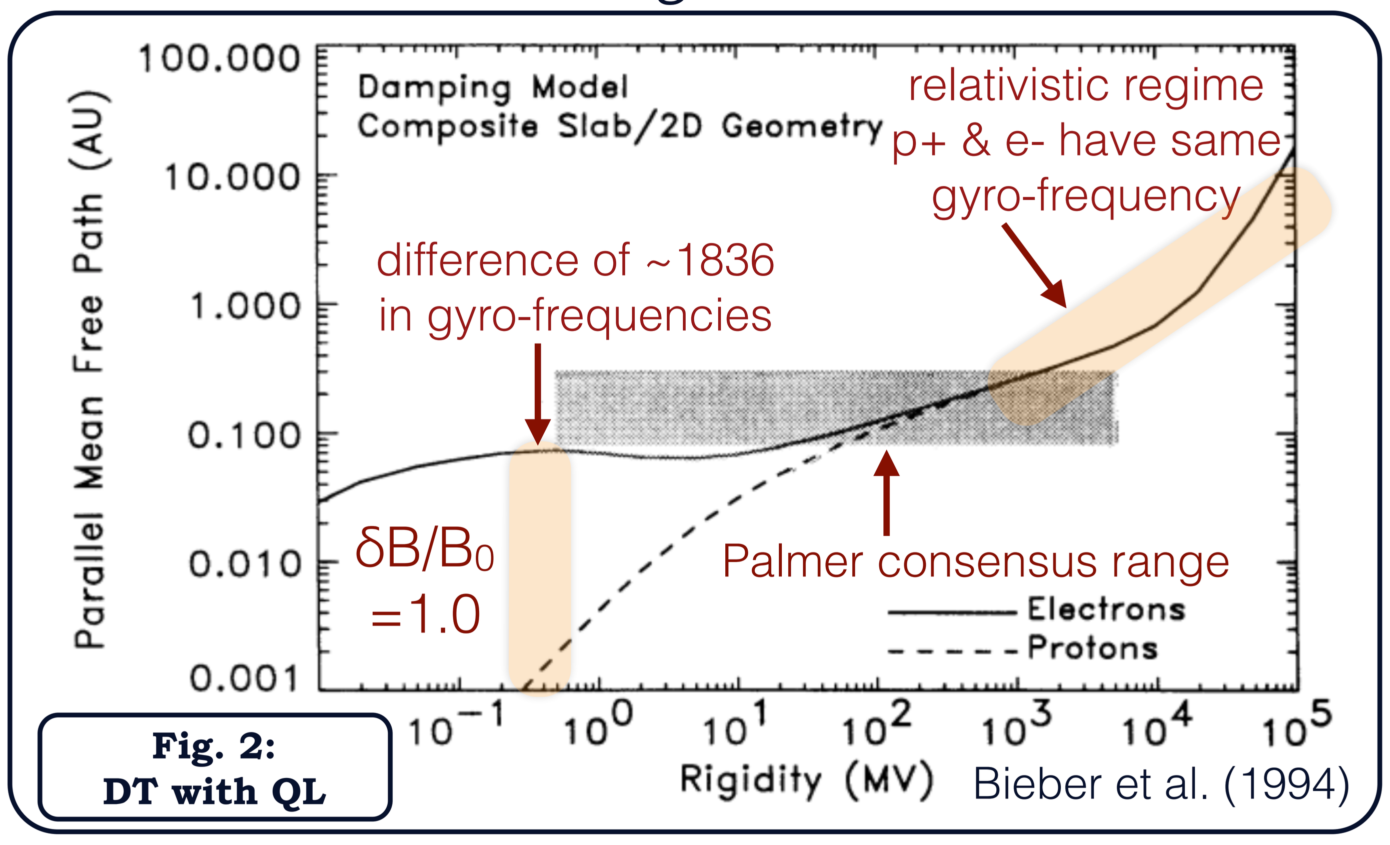


Fig. 2: DT with QL

Dynamical Turbulence

Tracking energetic particles in realistic solar wind dynamical turbulence is our aim. Turbulence is described by the Fourier or wavenumber space correlation tensor[3]

$$P_{mn}(\vec{k},t) = \left\langle \delta B_m(\vec{k})\delta B_n^*(\vec{k}) \right\rangle \Gamma(\vec{k},t)\,.$$

$\Gamma(\mathbf{k},t)$ is the dynamical correlation function where different models have been proposed. In this work we consider the damping model[2] which is indeed the most relevant

$$\Gamma(\vec{k},t) = e^{-\alpha v_A |\vec{k}| t}.$$

α: dynamical strength
v_A: Alfvén speed

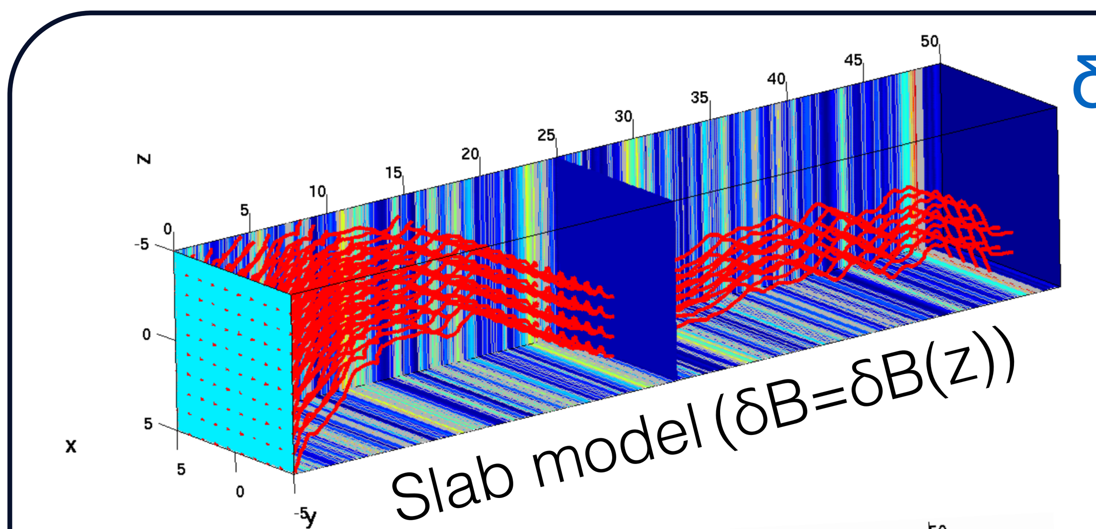
To calculate the Fourier transformed dynamical function we consider

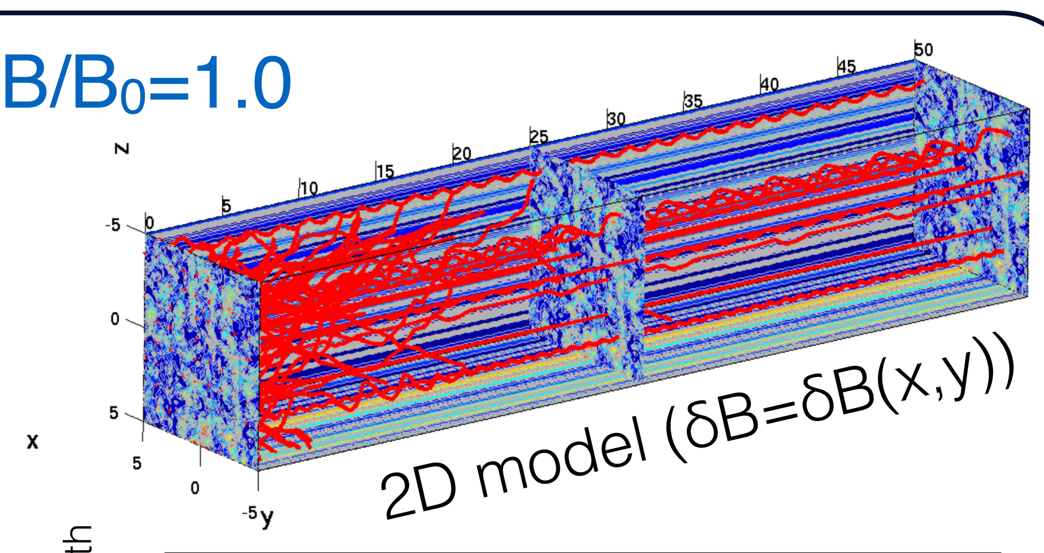
$$\chi(\vec{k},\omega) := \frac{1}{\pi}\Re\int_0^\infty dt\,\Gamma(\vec{k},t)e^{-i w t} = \frac{1}{\pi}\frac{\alpha v_A|\vec{k}|}{(\alpha v_A|\vec{k}|)^2 + \omega^2}\,.$$

Test-particle simulations & results

We performed simulations with pure slab[4] and slab/2D composite model with real solar wind parameters, table 1. Trajectories of 10^4 particles were calculated and averaged to yield diffusion coefficients. Ferreira el al. (2001) used Palmer (1982) results to calculate the ratio of the perpendicular to the parallel mean free paths. They found $\lambda_\perp/\lambda_\parallel$=b and 0.005<b<0.05.

$\delta B/B_0$=1.0





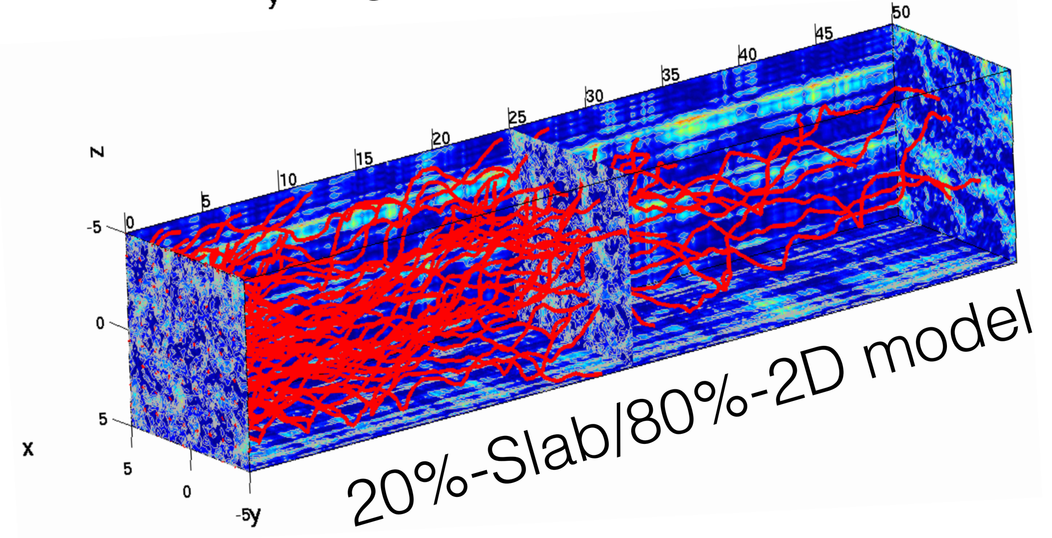
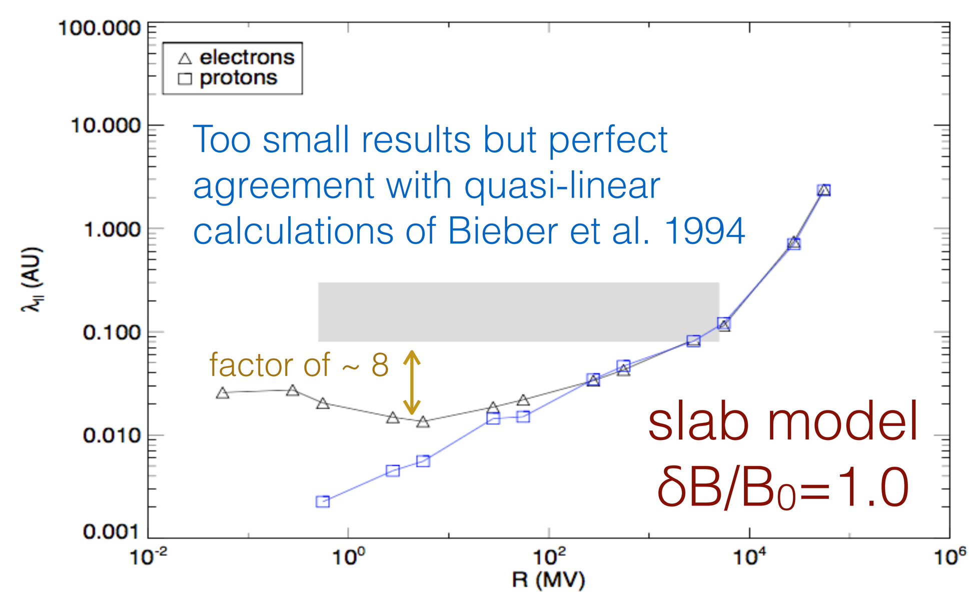
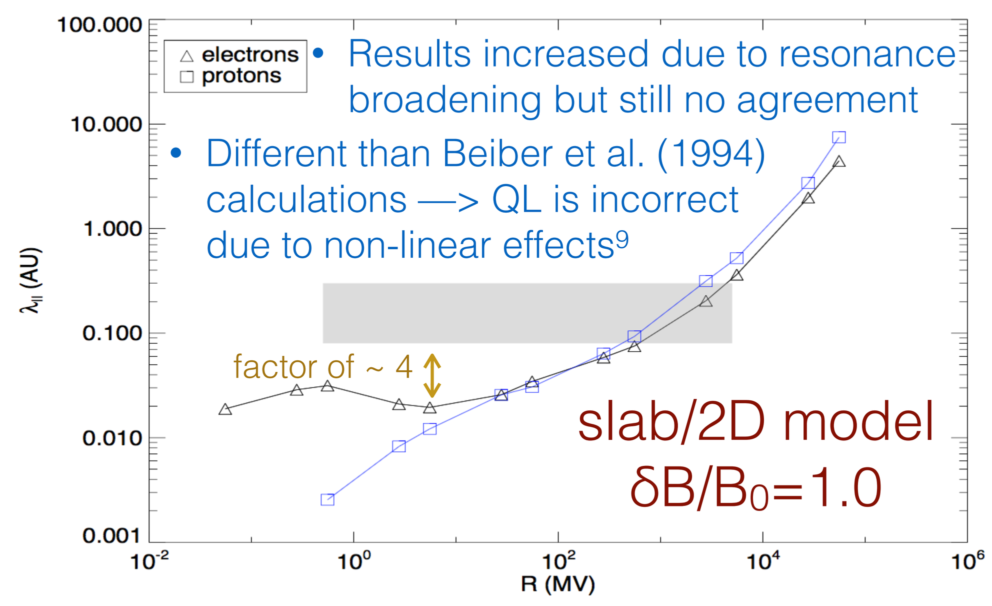
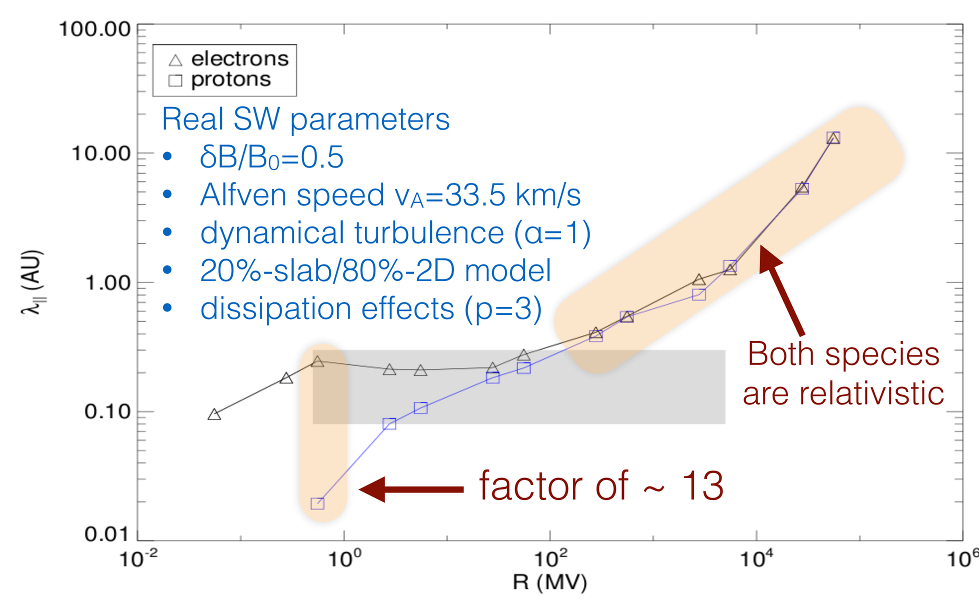


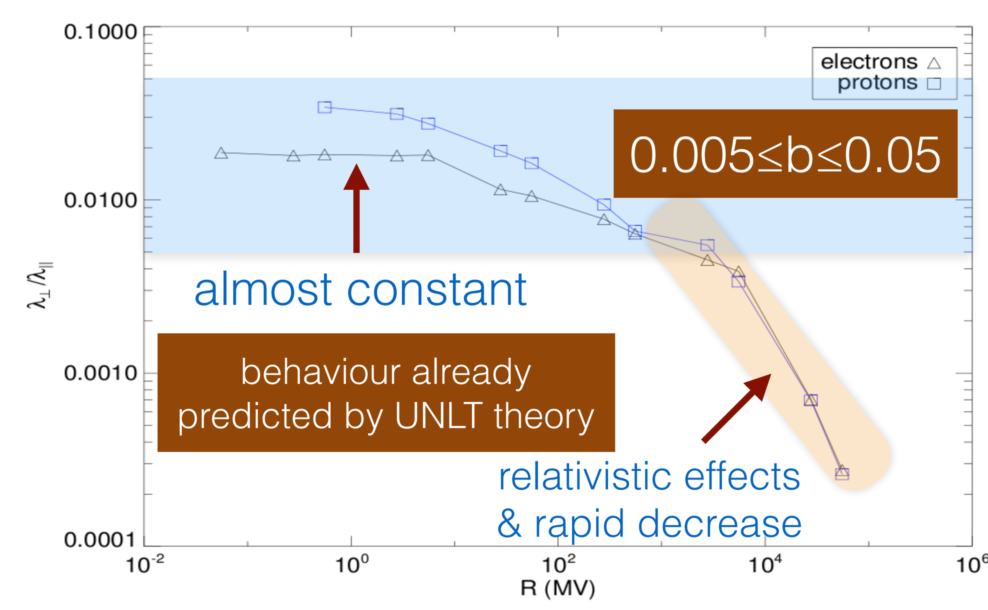
Table 1: Simulation parameters in agreement with solar wind values at 1AU

Parameter	Symbol	Value
2D energy range spectral index	q	2
Inertial range spectral index	s	5/3
Dissipation range spectral index	p	3
Alfvén speed	v_A	33.5 km/s
Slab bendover scale	l_{slab}	0.030 AU
2D bendover scale	l_{2D}	0.030 AU
Dissipation wavenumber	k_d	3×10^5 1/AU
2D dissipation wavenumber	k_{2D}	3×10^5 1/AU
Mean field	B_0	4.12 nT
Slab fraction	δB^2_{slab}	$0.2\ \delta B^2$
2D fraction	δB^2_{2D}	$0.8\ \delta B^2$









- No ability to reproduce the consensus band by employing the slab model
- The usage of the slab/2D model is required
- Rigidity is not the only property that influences the MFP
- Only $\delta B/B_0$=0.5 can reproduce Palmer (1982) results as suggested by Ruffolo et al. (2012)
- The behaviour of the MFPs ratio is exactly what is predicted by the UNLT theory[7,8]

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