Particle transport in MHD Turbulence

Study of cosmic ray propagation and dust grain acceleration

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In Short

- Turbulence properties, in particular, proportion of individual plasma modes change with driving
- Cosmic rays are superdiffusive on small scales and diffusive on large scales. Alfven modes are responsible for superdiffusion whereas compressible modes are responsible for more scattering.
- Particle scattering and acceleration is due to gyroresonance, TTD and different modes contribute differently.
- We intend to study these predictions numerically.

Cosmic rays(CR) are very high energy particles in the universe and are of non-thermal origin. The transport of cosmic rays through interstellar space is an ongoing subject of research in high energy astrophysics. The transport of particles through magnetic turbulence which pervades the interstellar/intergalactic medium is a fundamental physical process responsible for particle scattering and acceleration, CR diffusion, grain acceleration, CR anisotropy, positron transport, diffuse gamma ray emission etc.

MHD turbulence comprises of the compressible fast and slow modes and the Alfven modes. The driving mechanism of turbulence determines the proportion of the component modes present in turbulence[1]. The particle transport in turbulence depends upon the proportion of individual modes present in it as they interact differently with different modes [2] [3]. Also they are expected to show different diffusive behavior in position space on interaction with different eddy scales in turbulence. While the transport is diffusive on large scales, on smaller scales Richardson diffusion is expected. Additionally, particle acceleration could occur due to gyroresonance or transit time damping mechanism in turbulence. The particle acceleration is also expected to behave differently in different decomposed modes in turbulence[4].

Space plasma observations indicated superdiffusion rather than subdiffusion for perpendicular transport. Careful studies based on the GS95 model of turbulence indicated that particle is diffusive at large scales and superdiffusive at small scales[5]. Numerical simulations performed by [6] demonstrated this claim but used the mixed modes of MHD turbulence primarily due to solenoidal driving. We propose to further extend this investigations by looking at interactions with each individual decomposed present in MHD turbulence to distinguish the role of each mode in particle transport. Further we want to test particle transport in turbulence generated from various driving mechanisms. Since the earlier analysis was done using solenoidally driven turbulence only, we propose to extend the investigation to turbulence generated from more compressible driving. The investigations has to be carried out for turbulence with varying Mach nos from sub-Alfvenic to super-Alfvenic regimes. Also earlier analysis was done with respect to the global magnetic field direction. We intend to move to local field analysis in our simulations. Furthermore we intend to test interactions of particles with different energy/gyro radius in turbulence so that it falls in the inertial range. Earlier simulations were performed with gyro radius in the dissipation range which does not give accurate information.

Another investigation would be the acceleration of particles in MHD turbulence. Due to the similarity of the dust and cosmic ray scenarios, the results of these studies are of interest to the present investigation. The aim of the proposed study is to build on previous numerical simulations by studying the interaction of test particles and turbulence driven with general compressible forcing. More specifically, the project will focus on investigating the acceleration of dust grains, with the secondary aim of confirming the analytical predictions of [7]. The particle acceleration is also expected to behave differently in different decomposed modes in turbulence. The particle properties like initial charge to mass ratio and drag time is expected to influence particle acceleration in directions parallel and perpendicular to the magnetic field.

We intend to perform test particle simulations in order to obtain the trajectories of particle in MHD turbulence and evaluate the statistical properties of their transport. The particle tracer method follows the Bulrisch Stoer algorithm to solve the ODE and this method uses the adaptive time step where the total energy of the particle remains conserved to a high degree. The MHD turbulence can be generated with the fluid dynamics code PLUTO [8] which solves mixed hyperbolic/parabolic systems of partial differential equations (conservation laws) using a variety of finite-difference and finite-volume techniques based on Godunov schemes and is best suited for high Mach no flows in astrophysics. Using PLUTO the idea is to drive turbulence by the Ornstein-Uhlenbeck(OU) process.

We present 50 particle trajectories from a test particle simulation here in Fig 1a. A time snap of a 3D MHD turbulence data cube(Mach no 0.73) comprising of mixed modes(varying amount of fast slow and Alfven modes) is used here. The particles follow the magnetic field lines as shown in Fig.1a. Fig 1b shows the perpendicular diffusion coefficient of particles in MHD turbulence. This is obtained from the statistical analysis of the particle trajectory data obtained from test particle analysis. The results indicate that the particles undergo super diffusion at small scales and normal diffusion at large scales.

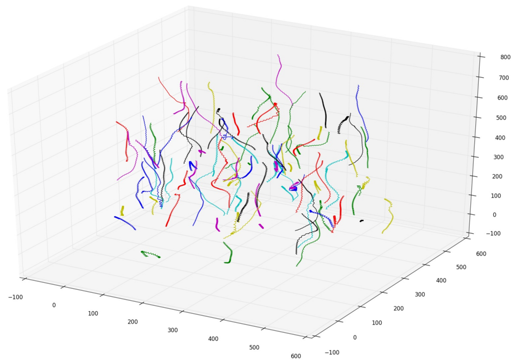

Figure 1: *50 particle trajectories obtained from test particle simulations in MHD turbulence of MA0.73 is presented here.*

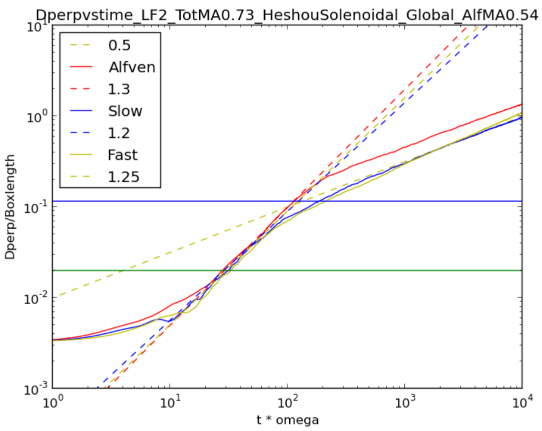

Figure 2: *The perpendicular transport/diffusion coefficient of particles which reveals the superdiffusive behaviour at small scale interactions and diffusive behaviour at large scale interactions is presented here.*

To summarize, the purpose of the proposed simulations are to test the nature of particle transport in different kinds of turbulence with different driving mechanisms and varying Mach Nos. We would like to primarily distinguish interactions of particle with different individual modes at different eddy scales. Another important investigation would be the difference between parallel and perpendicular transport with respect to the mean magnetic field. All these detailed studies has not been done earlier using numerical simulations. The statistical properties of particle transport could be obtained from the particle trajectories by calculating various diffusion coefficients. All these studies requires a considerable amount of parallel processing to run each simulation faster and a large amount of memory space to contain and process the large volume of data generated. In addition a lot of simulations are required to be performed to vary different parameters and test different types of turbulent data cubes affecting the transport of particle. As evident we have a variety of simulations to perform and each requires more computing time and resources. The proposed work could be accomplished with more effect with the requested computational resources.

WWW

https://www-zeuthen.desy.de/ hyan/

More Information

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Project Partners

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