# Seminar

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# Institute for Plasma Research

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**Title:** Astrophysical MHD turbulence and Cosmic ray transport

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**Date:** 10th July 2023 (Monday)

**Time:** 03:30 PM

**Venue:** Online

Online Link: https://meet.ipr.res.in/join/6599307740?be_auth=MzMxNDA5

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## Abstract

Cosmic-rays (CR) are energetic charged particles from outer space and their origin and propagation are big questions in the astroparticle physics community. Since MHD plasma turbulence is ubiquitous in astrophysical mediums such as the interstellar medium, CR transport is strongly dependent on the properties of MHD turbulence and therefore the advances in studies of CR transport goes hand in hand with the advances in studies of MHD turbulence. The results from a systematic study of cosmic-ray transport in numerically tested compressible magnetohydrodynamic (MHD) turbulence and its decomposed MHD modes will be presented. Test particle simulations were carried out to study the interactions of CR with both total MHD turbulence and decomposed MHD modes. CR transport studies in decomposed MHD modes were carried out for the first time. The mean free path ($\lambda_\|$) of CR were varied in different simulations and their interactions with Alfv´en, slow and fast mode turbulence were studied independently. The interactions were studied with both large and small scales of turbulence and having different Mach Nos. The spatial diffusion coefficients and the pitch angle scattering diffusion coefficients were calculated from the test particle trajectories in turbulence. The pitch angle studies confirms that the fast modes dominate the CR propagation, whereas Alfv´en, slow modes are much less efficient with similar pitch angle scattering rates. This is useful in explaining confinement of galactic CRs. The possible role of various resonant and non resonant interaction mechanisms in scattering were observed. The cross field transport on large and small scales were investigated next. On large/global scales, normal diffusion is observed and the diffusion coefficient is suppressed by $M^\zeta_A$ compared to the parallel diffusion coefficients, with $\zeta$ closer to 4 in Alfv´en modes than that in total turbulence as theoretically expected. For the CR transport on scales smaller than the turbulence injection scale, both the local and global magnetic reference frames were adopted. Super diffusion is observed on such small scales in all the cases. Particularly, CR transport in Alfv´en modes show clear Richardson diffusion in the local reference frame. The diffusion transition smoothly from the Richardson's one with index 1.5 to normal diffusion as particle's mean free path decreases from $\lambda_\| > L$ to $\lambda_\| < L$, where L is the injection/coherence length of turbulence. These results have broad applications to CRs in various astrophysical environment.

Next, the properties of compressible fast modes MHD turbulence will be presented which were studied via numerical simulations and independent of other MHD modes. The results from calculations of energy cascade rate of fast mode turbulence along various scales and different directions will be presented. High resolution 3D numerical simulations were performed using the astrophysical fluid dynamics solver PLUTO to generate fast mode turbulence. Wave vectors were injected in two different ways: collinearly and isotropically in two kinds of simulations. For the more realistic case of isotropic injection the plasma beta was varied in different kinds of simulations. The values of the wavevectors were varied in different simulations for all these cases to generate turbulences of different kind. The 1D energy spectral density of turbulence generated reveals that the spectral index of the velocity and the magnetic field has a value of -2 for high beta case resembling shocks or Burger's turbulence. For low beta case the magnetic field and the velocity field has a spectral index of -1.5 resembling weak acoustic turbulence. The spectral index of fast mode turbulence has been a debatable topic. The 2D energy spectrum and structure function calculations confirms the isotropy of fast modes. The energy cascading rate in fast modes and its directional dependence on the wave vectors will be presented. The results from simulations to distinguish between energy cascading in balanced and imbalanced turbulence will be presented. While imbalanced turbulence cascades faster compared to balanced turbulence in 1D turbulence this difference is not seen in 3D turbulence simulations. Understanding the properties of fast mode MHD turbulence like its energy spectral density and cascading rates has important implications in explaining cosmic ray scattering by them.