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Seminar

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Institute for Plasma Research

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Title: Turbulent dynamo action in a 3-dimensional magnetohydrodynamic plasma

Speaker: Mr. Shishir Biswas
Institute for Plasma Research, Gandhinagar

Date: 17th April 2024 (Wednesday)

Time: 03:30 PM

Venue: Seminar Hall, IPR

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Abstract

Turbulence is a ubiquitous phenomenon in nature and is considered to be one of the unresolved issues in physics. Turbulent velocity fields are known to have a crucial role in the production and maintenance of large-scale magnetic fields in different astrophysical objects. Multiple laboratory experiments and numerical investigations have been conducted to gain a comprehensive understanding of structure of magnetic field in astrophysical phenomena. Significant challenges involve the production of mean, or large-scale and small scale magnetic fields in celestial and astrophysical entities. Dynamo action [1], in which these multi-scale magnetic fields are produced as a result of turbulent velocity field motion, provides a potential explanation for the mechanism underlying this generation of magnetic energy. It is thus essential that the velocity fields possess sufficient dynamics to produce dynamo action. Understandably, not all velocity fields have the ability to generate dynamo action, as demonstrated by Crowling's and Zeldovich's anti-dynamo theorems.

In this Thesis work, we have initially examined the turbulent characteristics of different flows in both two and three dimensions [2, 3]. The inuence of fluid helicity on kinematic dynamo action has been studied utilizing these flow fields. According to conventional understanding, for a large scale or mean field dynamo, a lack of reectional symmetry (e.g., non-zero fluid or kinetic helicity) is required, where as for small scale or fluctuation dynamo it is not. By utilizing direct numerical simulation, we demonstrate that by controlled injection of fluid helicity, a systematic route emerges that connects “non-dynamo” to “dynamo” regime [4]. Time-averaged magnetic energy spectrum, for various magnitudes of injected fluid helicity is calculated and it is observed that, the spectra contain a visible maxima at a higher mode number, which is an important distinguishing feature of small scale dynamo (SSD) [4]. However for a nonlinear dynamo or self-consistent dynamo model, the nonlinear effects start to change the flow (once the magnetic field is large enough) to stop further growth in magnetic field energy, i.e, the flow and magnetic field “back react” on each other. The influence of helical and non-helical drive in such a nonlinear or self-consistent dynamo model is shown to have some crucial dynamics [5]. Evidence of small-scale dynamo (SSD) activity is found for both helical and non-helical drives [5]. The spectrum analysis shows that the kinetic energy evolution adheres to Kolmogorov's $k^{-5/3}$ law, while the magnetic energy evolution follows Kazantsev's $k^{3/2}$ scaling. These scalings are observed to be valid for a range of magnetic Prandtl numbers (P_m) [5].

Shear flows [2] often coexist in astrophysical conditions and the role of flow shear on the onset of dynamo is only beginning to be investigated. The paradigm of investigation of the exponential growth of magnetic field caused by the interaction of small-scale velocity fluctuations and a flow shear; is commonly referred to as the \shear dynamo problem" [6]. We have investigated the shear dynamo action using a kinematic dynamo model. For helical base flows, flow shear is shown to effectively suppress small-scale dynamo activity across a wide range of the magnetic Reynolds number. This mechanism is known as the suppression mechanism. We report several new findings, when a non-helical flow is used as the base flow. Specifically, we find that in the ab-

sence of shear flows, the considered non-helical flow is unable to induce exponential amplification of magnetic energy. Interestingly, when the flow shear is introduced, it is found that the small scale non-helical base flow produces magnetic energy that grows exponentially with time. We obtain an algebraic (combination of linear and non-linear) scaling, for the growth rate of magnetic energy with shear flow strength [6].

We have performed the above said studies using an in-house developed, multi-node, multi-card GPU based weakly compressible 3D Magnetohydrodynamic solver (GMHD3D) [7, 8]. Details of this study will be presented.

References:

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