Nonlinear studies in fluid dynamics: Phase synchronization models to explain energy bursts and spatiotemporal chaos in turbulence models.

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In this project the selected student will study nonlinear phenomena in fluid dynamics, using phase-coupling models and methods from complex networks and synchronisation, recently developed by the supervisor,[1] in scenarios of increasing complexity, such as:

(1) Understanding bursts of energy transfers in shell models of magneto-hydrodynamics (MHD) turbulence. Tasks will include:

- Theoretical and numerical work go hand-in-hand: you will familiarise yourself with the classical MHD shell models from the theoretical and numerical points of view, with emphasis on the case resembling the full 3D MHD case.
- Starting from these shell models, you will develop the so-called phase-only models, which basically freeze the amplitudes of the complex variables, letting only their phases evolve, hence the name.
- You will investigate these phase-only models numerically and will search for scenarios that lead to chaotic behaviour. For this, you will apply numerically the theory of dynamical systems to calculate Lyapunov exponents and other characterisations such as attractor dimension.
- You will compare these results against statistical studies of phase synchronization that you will conduct. Of utility will be a control parameter such as the exponent of the energy spectrum (the latter is stationary).

(2) Understanding the spatially- and temporally-localised structures (e.g. puffs, slugs, turbulence patches) that appear in pipe flow[2] and plane Couette flow[3], again in terms of phase-coupling models. Tasks are analogous to those in (1), with the following additions:

- Exploring chimera state regimes, namely where ordered and chaotic regions coexist.[4]
- Studying the effect of varying the aspect ratio on the level of phase synchronisation.

The selected student is expected to be a strongly motivated self-starter, and is expected to have a fair amount of knowledge of (and interest in) analytical and numerical methods on partial differential equations and systems of ordinary differential equations.

Periodic progress meetings and discussions with the supervisor, including task assignments, will take place either in person or remotely, depending on the circumstances. You will be part of a team where you will be able to interact with other PhD students and with senior researchers, thus gaining invaluable insights and knowledge.

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[1] https://dx.doi.org/10.1103/PhysRevResearch.4.L032035
[2] https://doi.org/10.1073/pnas.0909560107
[3] https://doi.org/10.1103/PhysRevLett.94.014502
[4] https://doi.org/10.1142/S0218127414400148