How is the dynamo generated in fluids, stars and planets?

PhD thesis/internship at LIMSI (Orsay)

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Dynamo action, i.e. the self-amplification of a magnetic field by the flow of an electrically conducting fluid, is considered to be the main mechanism for the generation of the magnetic fields of stars and planets [1]. However, the global mechanism for generating magnetic fields in the Universe is still elusive. To make progress, several liquid-metal dynamo experiments have been built, allowing observation and study of several regimes of astrophysical or geophysical interest. Among these experiments, the von Kármán Sodium experiment (VKS) has reproduced several dynamo regimes observed in the Universe, including a dynamical regime involving time-reversals like those undergone by the Earth's magnetic field. This set-up consists of a cylinder closed by two impellers at the top and bottom of the vessel (see top figure). The impellers rotate in opposite directions and drive a turbulent flow of liquid sodium up to Reynolds numbers Re $\sim 10^6$-10^7. Here also, a clear idea of the dynamo mechanism is still missing and local measurements of velocity and magnetic fields are difficult to perform. It is natural then to turn to computer simulations to gain some insight into the dynamos of VKS and more generally, of stars and planets.

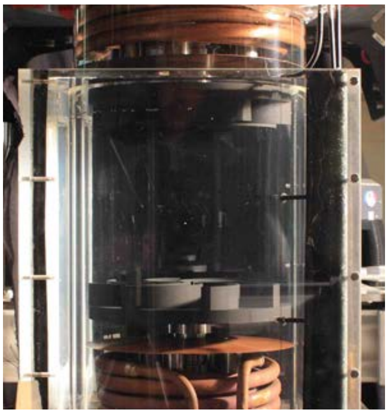
The objective of this internship/PhD is to numerically study the von Kármán flow driven in a liquid metal with a 3D code integrating the magnetohydrodynamic equations (Navier-Stokes equations coupled to Maxwell's equations). We have already reproduced the observed dynamo which is characterized by a mostly axisymmetric axial dipole with an azimuthal component concentrated near the impellers [2] (see bottom figure). The objective of the internship/PhD is to study in detail the local energy transfers between the kinetic and the magnetic energies to gain insight into the local dynamo mechanisms.

The student will first have to master the code that we have been developing since 2001 called **SFEMaNS**. It has been well validated [3] and can address various topics such as rotating flows or magnetic field generation in the inner liquid core of the Earth. The student will learn about various numerical methods and will validate the results of the numerical simulations by comparing them with recent results. The runs will be performed on massively parallel computers. The internship/PhD program is both theoretical and applied and will allow the student to expand his/her knowledge in fluid mechanics, magnetohydrodynamics, turbulence and High Performance Computing (HPC).

Keywords: Fluid mechanics, turbulence, numerical and computational methods, magnetohydrodynamics.

Candidate profile: Good expertise in fluid mechanics; good computer skills are mandatory. Magnetohydrodynamics is not a prerequisite.

This internship can be extended to a PhD thesis, with visits to math department of TAMU (USA) for extended periods.



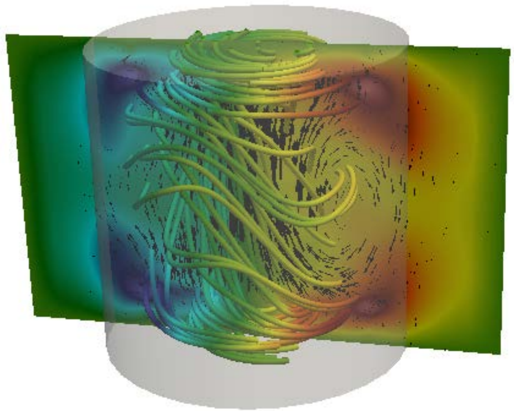


Figure : (top) von Kármán Experiment in water (SPEC-CEA) and numerical simulation with SFEMaNS (LIMSI): Magnetic field lines in the numerical von Kármán Sodium experiment (VKS) colored by the azimuthal component.

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Supervision and collaboration:

The internship/PhD will take place at LIMSI (Univ. Paris Sud, Univ. Paris Saclay) and SPEC (CEA Saclay), with visits to College Station in Texas. It will be supervised by C. Nore (LIMSI, professor Univ. Paris Sud) and B. Dubrulle (DR CNRS, SPEC and CEA) with the collaboration of J-L. Guermond (Texas A&M University). The student will have the opportunity to visit the **department of Mathematics of TAMU** (Texas, USA) for extended periods with J.-L. Guermond (between 3 months and one year during the PhD thesis-all expenses paid).

References:

[1] H. Moffatt. *Magnetic Field Generation in Electrically Conducting Fluids*. Cambridge Monographs on Mechanics and Applied Mathematics. Cambridge University Press (1978).

[2] C. Nore *et al.,* Journal of Fluid Mechanics, 854, pp. 164-195 (2018).

[3] J.-L. Guermond *et al.,* Journal of Computational Physics, 230, p. 6299-6319 (2011).