# Statement of Research

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Dr. Benjamin FAVIER

Department of Applied Mathematics and Theoretical Physics
Centre for Mathematical Sciences
Wilberforce Road, Cambridge
CB3 0WA, United Kingdom
*Email*: b.favier@damtp.cam.ac.uk
*Web site*: http://sites.google.com/site/bfavierhome/
*Phone*: +44 (0)1223 760393

In a broad outline, my research interests lie in the study of astrophysical fluid dynamics. I am mostly using high-resolution numerical simulations running on massively parallel architectures. My PhD dissertation was devoted to the distortion of turbulence by background rotation and an imposed magnetic field. I then worked on the dynamo properties of rotating compressible convection and I am currently working on various aspects of the solar dynamo cycle (from convectively-driven dynamos to magnetic buoyancy) and forced inertial modes in spherical shells (with applications to the tidal dissipation problem in giant planets). I present here how my research interests could integrate within the Astrophysics group of the University of Exeter thanks to the position P44453/P44454.

## Past research interests

In many astrophysical flows, turbulence is affected by forces that distort significantly some of its scales in an anisotropic manner. The response of homogeneous turbulence to the Coriolis, Lorentz or buoyancy forces, considered independently or simultaneously, is of major interest for many natural flows, such as the atmosphere, the ocean, the melted iron core of the Earth, the solar wind... While computing the global dynamics of these flows is a tremendous task, the understanding of the local dynamics is accessible and crucial to develop realistic models.

During my PhD dissertation, I numerically studied various aspects of homogeneous incompressible turbulence submitted to background rotation, density stratification and/or an imposed magnetic field. This work was published in several articles [1, 2, 3, 4, 5]. I learnt how to use massively-parallel codes, I familiarised myself with various spectral methods and models of turbulence (pseudo-spectral Direct Numerical Simulations, Eddy Damping Quasi-Normal Markovian models, ...), and I finally studied various configurations involving magnetohydrodynamic turbulence.

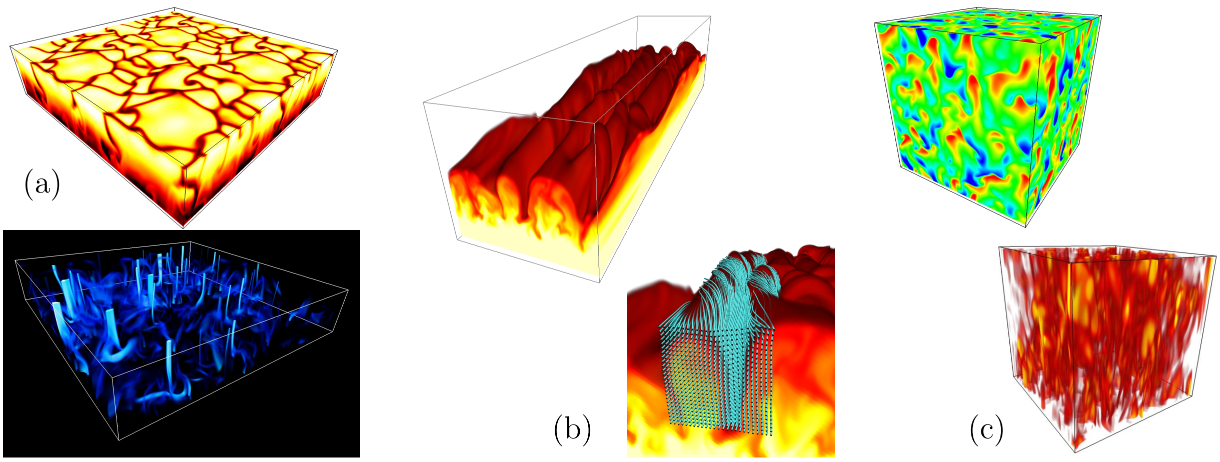


Figure 1: (a) Temperature fluctuation and magnetic energy in rotating compressible convection. (b) Magnetic buoyancy instability of a horizontal layer interacting with a weakly magnetized atmosphere. (c) Enstrophy in turbulence submitted to a vertical magnetic field at low magnetic Prandtl number (bottom) and temperature fluctuations in homogeneous Rayleigh-Bénard convection.

The context of homogeneous turbulence is well-suited to understand the fundamental dynamics but often lacks realistic applications, since boundary conditions are discarded and forcing can be unrealistic. Having these ideas in mind, I tried to find a post-doctoral position allowing me to work on a more realistic configuration, but in which my previous skills would be put to contribution. I obtained a Research Associate position at Newcastle University under the supervision of Dr. Paul Bushby. Motivated by open questions in fundamental dynamo theory, the overall aim of my post-doctoral position was to investigate the properties of dynamo action in rotating compressible turbulent convection with application to solar-type stars and their surface magnetism. We investigated convectively-driven dynamos in several distinct regions of parameter space (see figure 1(a)), and we establish the dependence that any dynamos have upon the stratification and the rotation rate [6, 7]. Finally, we also considered the effect of mesogranulation, a large-scale flow generated by the nonlinear interaction of convective granules, on dynamo action and particle advection. We have shown how kinematic dynamo action is favoured by the presence of mesogranulation, and how small-aspect ratio simulations of convection can miss this effect [8].

Since October 2011, I am working as a Research Associate at the Department of Applied Mathematics and Theoretical Physics in Cambridge, under the supervision of Prof. Michael Proctor. I am working on various problems related to solar dynamo theory. In particular, we are studying new configurations in which twisted magnetic structures are emerging naturally from buoyancy instabilities [9] (see figure 1(b)), with applications to the emergence of deep-seated toroidal magnetic fields in solar-type stars. From a more fundamental point of view, we also recently study the adjoint dynamo problem and its consequences concerning the dependence of dynamo action on boundary conditions in sodium experiments [10]. We also consider the kinematic dynamo action in hexagonal and square patterns of convection [11] and pursue our work on mesogranulation.

## Current research activities

I develop here some of the projects I am currently working on. This on-going and unpublished research is presented here in order to give the reader a better view of my expertise and to show my ability to lead innovative research independently or within a collaboration.

### Magnetic fields, shear and deep convection

The first project is dealing with the nature and properties of the convection in the solar tachocline region, which is one of the main remaining unknown in the solar dynamo theory. In particular, many physical processes, such as turbulent pumping of magnetic fields, are derived from local numerical simulations of convection spanning a few pressure scale heights only [12]. With Paul Bushby, we are therefore studying the effect of increasing the vertical extent of plane-layer models of compressible convection. One could argue that global spherical simulations are now accessible [13, 14], but these simulations still lack the resolution needed to properly resolved magnetic buoyancy and small-scale convection.

A local model is therefore still of interest, and allows to investigate the interaction with shear and magnetic fields with this deep convection. The results obtained could also be used as diagnostic data to inform future work in helioseismology on the relation between solar surface flows and the deeper structure of the convection.

### Tidal dissipation in planets

With now more than 800 known exo-planets, the interaction between these planets and their host stars is of increasing interest. In particular, the tidal interaction and associated dissipation is of importance to understand the evolution of the orbital parameters. Most of the studies on the dynamical response of a fluid inside a spherical shell have focused on the linear regime. The corresponding inertial eigenmodes show very rich behaviours and a strong dependence on the Ekman number and on the frequency of the forcing potential.

It is known that the nonlinear interaction of inertial waves in a spherical shell can lead to zonal flows or elliptical instabilities, and I am currently using the spherical harmonics code PARODY to study this problem. This is a collaboration with Adrian Barker (Northwestern Uni.) and Gordon Ogilvie (Cambridge). Preliminary results are very promising, with a rich range of zonal flows created and counter-intuitive trends, and this project could be extended to more realistic situations including interaction with magnetic fields, convective motions and compressible effects. An example of an inertial wave attractor is shown on figure 2(b).

To conclude, from local simulations of incompressible MHD or homogeneous convection "in a box" to more realistic dynamos driven by compressible convection and simulations in spherical shells, I am interested in a wide range of hydrodynamic and magnetohydrodynamic phenomena with applications to planetary and stellar interiors. My expertise in a wide range of hydrodynamical and magnetohydrodynamical simulations is in complete adequacy with the fellowship proposed by the Astrophysics groups of the University of Exeter.

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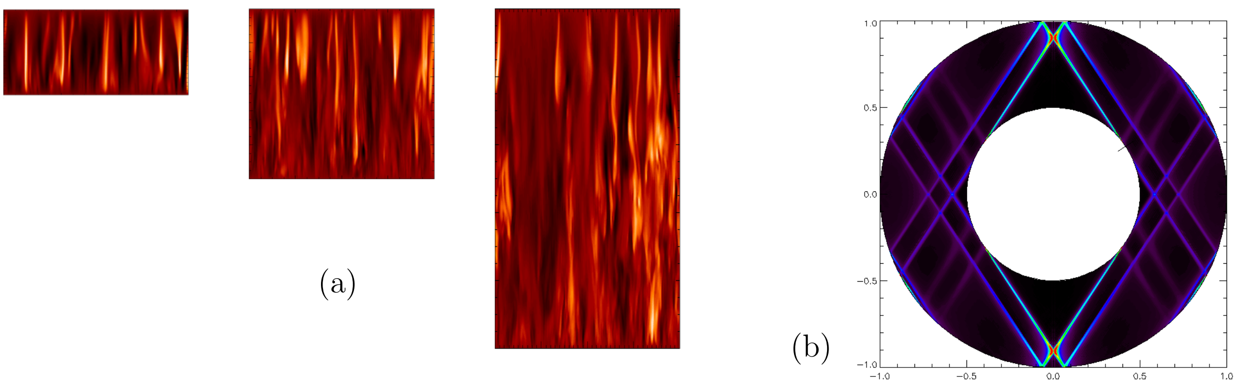


Figure 2: (a) Side view of the temperature field in compressible convection. We gradually increase the vertical extend of the domain. (b) Velocity magnitude in a meridional plane of a spherical shell. The flow is forced by a radial velocity at the outer boundary to mimic the tidal deformation.

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