MREP 2017 Book of Abstracts

As the local organising committee we are pleased to host this special 'MREP 2017' meeting in Cambridge. We meet to celebrate the work of Michael Proctor as he retires from his teaching role at the University. It is a pleasure to be able to welcome so many of Mike's friends and collaborators. We kindly thank DAMTP, King's College and the RAS for supporting the conference financially.

The meeting provides Mike's current and former collaborators with the opportunity to discuss work, both old and new, in research areas in which Mike has been influential. We also welcome participants who have interest in the topics on which Mike's work has focused - topics including convection, magnetoconvection, nonlinear dynamics, MHD, and dynamo theory.

We hope the meeting will provide ample opportunity to both stimulate interesting scientific discussion and reminisce on old times. King's College - where Mike is the current Provost - will host the conference dinner on Monday evening. Finally, we look forward to hearing predictions of the direction Mike's reasearch might take during the next 40+ years!

Robert Teed and Valeria Shumaylova

Local Organising Committee

ABSTRACTS

Listed below are the abstracts alphabetised by last name of presenting author.

Oral Presentations

Rotating convection with inclined gravity and rotation
Adrian Barker, Laura Currie, Yoram Lithwick, Matthew Browning*
**University of Leeds*

Thermal convection is influenced by rotation in the interiors of many planets and stars. But despite decades of research, a comprehensive theory of rotating convection has remained elusive. The structure of a star or planet is often modelled using mixing-length theory which, despite its simplicity, is capable of reproducing the key structural features of a convection zone. I will present the derivation of a simple mixing-length theory for rapidly-rotating convection in the polar regions of a star or planet, first derived by Stevenson (1979). This is validated using three-dimensional numerical simulations of Boussinesq convection in a Cartesian model with aligned gravity and rotation. I will then discuss the extension of both theory and simulations to cases where gravity and rotation are inclined, which is appropriate to model convection at other latitudes in a star or planet. Stevenson suggested that one could replace the rotation rate, Ω with $\Omega \cos\theta$ (where θ is the colatitude angle) in the theory. This prediction is tested using simulations that extend the pioneering calculations of Hathaway & Somerville (1983) to a more rotationally-dominated regime and with much smaller values of the diffusivities. I will also describe the importance of zonal flows (driven by the convection) in modifying the heat transport in non-polar cases.

The onset of rotating dynamos at the low Pm limit

Vassilios Dallas, Kannabiran Seshasayanan, Alexandros Alexakis*
**University of Leeds*

In this talk I will demonstrate that the critical magnetic Reynolds number Rm_c for a turbulent non-helical dynamo in the low magnetic Prandtl number Pm limit (i.e. Pm = Rm/Re << 1) can be significantly reduced if the flow is submitted to global rotation. Even for moderate rotation rates the required energy injection rate can be reduced by a factor more than 1000. This strong decrease of the onset is attributed to the reduction of the turbulent fluctuations that makes the flow to have a much larger cut-off length-scale compared to a non-rotating flow of the same Reynolds number. The dynamo thus behaves as if it is driven by laminar behaviour (i.e. high Pm behaviour) even at high values of the Reynolds number (i.e. at low values of Pm). Our finding thus points into a new paradigm for the design of new liquid metal dynamo experiments.

Mathematical research explaining patterns: from Trinity to King's

Jonathan Dawes,*
**University of Bath*

The mathematical theory of pattern formation in dissipative nonlinear systems has its origins in the work of Lord Rayleigh in the early twentieth century, and, separately, in the work of Alan Turing in the 1950s. Turing's 1952 paper is particularly highly regarded, having been cited over 5,000 times.

This presentation will mostly discuss Turing's later, far less well appreciated but far more ambitious, work which also sets the scene for modern approaches to the subject.

Large-scale dynamo and inverse cascade in rapidly-rotating Rayleigh-Bénard convection

Benjamin Favier, Michael Proctor*
**IRPHE CNRS*

In this talk, I will present two studies related to thermal convection in a horizontal plane layer rapidly-rotating around the vertical axis. Very close to onset, we consider the kinematic dynamo action driven by square and hexagonal patterns, and study the transition from large-scale to small-scale dynamos using both mean-field theory and numerical simulations. Far from onset, we show that it is possible to drive an inverse cascade in the purely hydrodynamical case, whereby large-scale cyclones filling the numerical domain are formed.

Optimization of the kinematic dynamo in cubes and spheres
W. Herreman, L. Chen, A. Jackson, K. Li, P. Livermore, J. Luo*
**LIMSI, Université Paris-Sud*

In recent years, we have conducted a research program on optimized kinematic dynamos that allowed us to numerically measure the minimal magnetic Reynolds number under which no kinematic dynamo is possible with general steady flows. In this talk, I will summarize our results and place them into the context of Michael Proctor's work on lower bounds for dynamo action. The mechanisms by which the optimal dynamos operate still remain unknown, but I will discuss some small insights.

Mean Responses to Symmetry Breaking Perturbations in Disordered Systems
*David Hughes**
**University of Leeds*

Mean field MHD considers the response of quantities such as the emf to symmetry-breaking perturbations such as the imposition of a uniform magnetic field. We first show how the traditional theory may be extended to consider perturbations to a dynamical MHD state. By showing how the response to purely kinematic perturbations may in certain circumstances be impossible to calculate, we then ask whether the response to a dynamical symmetry-breaking perturbation is linear in the perturbation, when this is sufficiently weak. This turns out to be surprisingly difficult to answer, not just for the complex system of MHD turbulence, but even for ostensibly much simpler one-dimensional maps.

Rotating magnetic waves in stably stratified layers
Chris Jones, Xiomara Marquez-Artavia, Steve Tobias*
**University of Leeds*

Waves in a thin layer on a rotating sphere are studied. The effect of a toroidal magnetic field is considered, using the shallow water ideal MHD equations. The work is motivated by suggestions that there is a stably stratified layer below the Earth’s core mantle boundary, and the existence of stable layers in stellar tachoclines. Magnetic instabilities can occur when the field is strong. Waves can be divided into magneto-inertial gravity waves, magneto-Kelvin waves, fast and slow magnetic Rossby waves. The properties of these waves will be discussed.

Investigating the magnetic dichotomy of A-type stars
Laurene Jouve, F. Lignières, T. Gastine, M. Gaurat, D. Meduri*
**IRAP Toulouse*

Some A stars (Ap stars) possess strong large-scale magnetic fields which seem to remain rather stable in time. Some recent observations now tend to show that another class of A stars exists, which exhibit a more complex and weak magnetic field, organized at smaller scales at their surfaces. We would like to understand this magnetic dichotomy by investigating the stability of magnetic fields created by differential rotation in the stellar radiative envelope. We numerically compute the joint evolution of the magnetic and velocity fields in a 3D spherical shell. In agreement with previously suggested scenarios, we find that after an Alfvén time, a maximum for the ratio of toroidal to poloidal fields is reached. Depending on this value, we will show that such magnetic configurations may or may not be subject to a magneto-rotational instability, which could explain the dichotomy between strong and weak observed magnetic fields in A-type stars. Cases where the differential rotation is forced and where hints of dynamo action in radiative zones are present will be discussed.

Dynamo quenching by shear flows

Eun-jin Kim, N. Leprovost, A. Courvoisie, A. Sood, R. Hollerbach*
**University of Sheffield*

The evolution of magnetic fields and shear flows is closely linked through their direct interaction and also by the indirect interaction through various transport mechanisms (alpha effects, momentum transport, etc). In this talk, I focus on one of such effects, that is, dynamo quenching by shear flows in different models including the kinematic dynamo driven by the Galloway-Proctor flow and nonlinear sheared MHD turbulence.

Electrovortex flow in external magnetic field

Irina Klementyeva, Igor Teplyakov*
**Joint Institute for High Temperatures of Russian Academy of Sciences*

Electrovortex flows are the part of many technological processes. For example they take place in the working areas of such industrial facilities as: electro-arc furnaces and reactors in metallurgy and waste recycling, electro-slag remelting and welding apparatus. Basically the described systems look like the following one: working area is a container filled with electro-conducting material, electric current passes through the melt from a rod electrode towards a volume one, there are systems with an electric arc between the rod electrode and the melt and without the electric arc, the electric current interacts with its own magnetic field and as a result under the action of electromotive body force the electrovortex flow is generated in the system. In the presence of external magnetic field there is also azimuthal rotation of the melt and additional secondary vortex structures appear.

We investigate the system experimentally and numerically. Numerical studies are carried out under the configuration corresponding to the experimental setup which consists of following elements: the copper hemispherical container filled with indium-gallium-tin eutectic alloy, serving as a volume electrode; the copper or steel rod electrode with hemispherical tip, immersed into the alloy. Direct electric current passes through the metal. External magnetic field is created by electromagnetic coil which is mounted coaxially with the hemispherical volume. Simulations are based on magnetohydrodynamic model in electrodynamic approach. The magnetic field of three-dimensional solenoid is numerically calculated and assumed as the external magnetic field in the system. Control volume method is used to solve three-dimensional non-stationary laminar Navier-Stokes equation. Velocity measurements are performed with the fiber-optic probe developed in our laboratory. The probe measures two components of the velocity in the working area.

It was found that complex flow exists in the volume under the conditions of consideration. The flow consists of two axially symmetric vortices rotating in opposite directions at the presence of azimuthal swirling. Structure, time and place of the formation of the electrovortex flow and the secondary vortex are strongly depends on electric current and external magnetic field values. The higher the external magnetic field and the lower the electric current the earlier the time moment of the generation of the secondary vortex.

Astronomical Immunology
Grant Lythe, Carmen Molina-Paris*
**University of Leeds*

There are approximately 400000000000 T cells in your body, about the same as the number of stars in our galaxy. We cannot manually count, let alone examine the interior machinery of, many cells or stars in situ. Those cells and stars that we can see, we only see at one instant of their long lifetimes. Instead, we have to rely on extrapolation from small samples and on indirect measurements, deducing what we can about processes in the interior from observations of their surface, imaging and data analysis, and computational models.

T cells are produced in the thymus and circulate through a human body, using T-cell receptors to probe the surfaces of antigen-presenting cells they come into contact with. How many different types of T cells do we have? The number of T cells of one type is an integer that increases or decreases by one cell at a time, when a cell divides or a cell dies. Immune responses rely on encounters between T cells and dendritic cells in lymph nodes.

Stochastic models of immune system dynamics, describing millions of cells that interact with each other and with their environment, are more realistic than deterministic ones. Fortunately, stochastic models are also practical because analytical and numerical methods, and open-source software, are available.

An unforced dynamo in an annulus
Jonathan Mestel, Raquel Vaz and Florencia Boshier*
**Imperial College London*

Some previously unreported solutions of the Navier-Stokes equations in a cylindrical annulus are presented. These are linear in the axial coordinate and governed by ODEs, but are otherwise unforced. It is shown that several of these flows can support a laminar dynamo with the same structure, and which can be followed into the nonlinear regime.

Some Non-Mirror-Symmetric Reflections on Dynamo Theory
*Keith Moffatt**
**University of* Cambridge

I shall review the role of helicity in dynamo theory, particularly in relation to the alpha-effect of mean-field electrodynamics, a field to which Michael Proctor has made great contributions. The problem of alpha-quenching at high magnetic Reynolds number is still particularly acute, and requires consideration of the effect of turbulence at scales below the threshold of observation in astrophysical contexts. This leads to consideration of the effect of weak molecular diffusivity in reconnection processes, on which some recent modest progress has been made. I shall conclude with comments concerning the complementary problem of magnetic relaxation under topological constraints, with reference to the conjecture of J.B.Taylor (1974).

Torsional Alfvén waves in a dipolar magnetic field

Henri-Claude Nataf, Zahia Tigrine, Nathanaël Schaeffer and Philippe Cardin*
**Univ Grenoble Alpes, CNRS, IRD, ISTerre, F-38000, Grenoble, France*

Among the many topics tackled by Mike Proctor, I chose a simple MHD problem: the excitation and propagation of Alfvén waves in a dipolar magnetic field. To make it fun (and planet-like), we add the effect of rotation. And to give it a french touch, we do it experimentally, and confront to numerical simulations.

The observation of torsional Alfvén waves in the Earth's core (Gillet et al, 2010) is a strong motivation for the investigation of the physics of these waves. Alfvén waves are difficult to excite and observe in liquid metals because of their high magnetic diffusivity. Nevertheless, we obtained clear characteristics of such diffusive waves in the DTS setup. In this setup, some 40 litres of liquid sodium are contained between a r_o = 210 mm-radius stainless steel outer shell, and a r_i = 74 mm-radius copper inner sphere. Both spherical boundaries can rotate independently around a common vertical axis. The inner sphere shells a strong permanent magnet, which produces a nearly dipolar magnetic field whose intensity varies from 175 mT at r_i to 8 mT at r_o in the equatorial plane.

We excite Alfvén waves in the liquid sodium by applying a sudden jerk of the inner sphere. To study the effect of global rotation, which leads to the formation of geostrophic torsional Alfvén waves, we spin the experiment at rotation rates $f_o = f_i$ up to 15 Hz. The Alfvén wave produces a clear azimuthal magnetic signal on magnetometers installed in a sleeve inside the fluid. We also probe the associated azimuthal velocity field using ultrasound Doppler velocimetry. Electric potentials at the surface of the outer sphere turn out to be very interesting as well.

In parallel, we use the X-shells spherical MHD code to model torsional Alfvén waves in the experimental conditions and beyond. We explore both linear and nonlinear regimes. We observe a strong excitation of inertial waves in the equatorial plane, where the Alfvén wave transits from a region of strong magnetic field to a region dominated by rotation.

Numerical simulation of the VKS dynamo experiment

Caroline Nore, Daniel Castanon Quiroz, Loïc Cappanera and Jean-Luc Guermond*
**LIMSI and Université Paris Sud*

We present hydrodynamic and magnetohydrodynamic (MHD) simulations of liquid sodium flow in the Von-Karman-Sodium (VKS) set-up. The counter-rotating impellers made of soft iron used in the successful experiment of 2006 are realistically modeled by means of a pseudo-penalization method and of a new algorithm based on the induction field. Hydrodynamic simulations are performed at high kinetic Reynolds numbers using a Large Eddy Simulation technique and results compare well with the experimental data: at small impeller rotation frequencies, the flow is laminar and steady or slightly fluctuating; at large frequencies, small scales fill the bulk and a Kolmogorov-like spectrum at large azimuthal wavenumbers is obtained. Near the tips of the blades the flow is expelled and takes the form of intense helical vortices. The equatorial shear layer acquires a wavy shape due to three coherent co-rotating radial vortices as observed in hydrodynamic experiments. MHD computations are performed and show that, at fixed kinetic

Reynolds number, increasing the magnetic permeability of the impellers lowers the critical magnetic Reynolds number for dynamo action and, at fixed impeller magnetic permeability, increasing the kinetic Reynolds number decreases the critical magnetic Prandtl number (ratio of the critical magnetic Reynolds number and the kinetic Reynolds number). Our results support the conjecture that the critical magnetic Reynolds number tends to a constant as the kinetic Reynolds number tends to infinity. The resulting dynamo is a mostly axisymmetric axial dipole with an azimuthal component concentrated in the impellers as observed in the VKS experiment.

Fluctuations of Electrical Conductivity: A New Source for Astrophysical Magnetic Fields
F. Pétrélis, C. Gissinger, A. Alexakis*
**Ecole Normale Supérieure*

We consider the generation of a magnetic field by the flow of a fluid for which the electrical conductivity is not uniform. A new amplification mechanism is found which leads to dynamo action for flows much simpler than those considered so far. In particular, the fluctuations of the electrical conductivity provide a way to bypass anti-dynamo theorems. For astrophysical objects, we show through three-dimensional global numerical simulations that the temperature-driven fluctuations of the electrical conductivity can amplify an otherwise decaying large scale equatorial dipolar field.

Reflections on 40 years of research: successes, disappointments and open questions
Michael R. E. Proctor
**University of Cambridge*

In 40 years since my first publication with Willem Markus I have been involved in a number of areas of applied mathematics, all broadly connected with magnetic fields, convection and bifurcations. I will talk about progress that I think I have made and also describe some questions that I would like to understand but whose answers remain outstanding.

Spirals and heteroclinic cycles in a spatially extended Rock-Paper-Scissors model of cyclic dominance
Alastair Rucklidge, Claire Postlethwaite*
**University of Leeds*

Spatially extended versions of the cyclic-dominance Rock-Paper-Scissors model have travelling wave (in one dimension) and spiral (in two dimensions) behavior. The far field of the spirals behave like travelling waves, which themselves have profiles reminiscent of heteroclinic cycles. We compute numerically a nonlinear dispersion relation between the wavelength and wave speed of the travelling waves, and, together with insight from heteroclinic bifurcation theory and further numerical results from 2D simulations, we are able to make predictions about the overall structure and stability of spiral waves in 2D cyclic dominance models.

Subcritical thermal convection of liquid metals in a rapidly rotating sphere
Nathanael Schaeffer, E. J. Kaplan, J. Vidal, P. Cardin*
**Univ. Grenoble Alpes / CNRS / ISTerre*

Planetary cores consist of liquid metals (low Prandtl number Pr) that convect as the core cools. Here we study nonlinear convection in a rotating (low Ekman number Ek) planetary core using a

fully 3D direct numerical simulation. At high rotation rate, the convection onsets in a turbulent state, and can be maintained well below the linear onset of convection (down to $Ra=0.7\ Ra_{crit}$ in this study).

We highlight the importance of the Reynolds stress, which is required for convection to subsist below the linear onset. In addition, the Péclet number is consistently above 10 in the strong branch. We further note the presence of a strong zonal flow that is nonetheless unimportant to the convective state. Our study suggests that, in the asymptotic regime of rapid rotation relevant for planetary interiors, thermal convection of liquid metals in a sphere onsets through a subcritical bifurcation.

Chiral dynamos in the Early Universe

Jennifer Schober, Axel Brandenburg, Igor Rogachevskii, Alexey Boyarsky, Oleg Ruchayskiy, Jürg Fröhlich, Nathan Kleeorin*
**LASTRO, EPFL*

Observations of blazar emission suggest that the intergalactic medium is permeated by large-scale magnetic fields. Most probably these are relics of primordial fields, the origin and evolution of which is still a mystery.

In this talk, I will present a modified theory of magnetohydrodynamics, which describes a relativistic plasma like the one in the early Universe. We include additional terms and equations in order to follow the dynamics of the chiral chemical potential, i.e. the asymmetry between left- and right-handed fermions. This asymmetry can give rise to a new electric current along the magnetic field, an effect known as chiral anomaly. Using high-resolution numerical simulations we study the amplification of weak magnetic seed fields shortly after the Big Bang. I will present different new dynamos which can operate in a relativistic plasma for both laminar and turbulent flows.

These results, which are constrained by present-day observations of the intergalactic medium, can help us to better understand the role of magnetic fields in the early Universe.

A scenario for dynamo bursts

Dmitry Sokoloff, E.Yushkov*
**Moscow State University*

In a framework of a simple model of geodynamo we present a scenario for dynamo bursts and reversals of geomagnetic dipole.

Of Mikes and Butterflies

Frank Stefani,*
**Helmholtz-Zentrum Dresden-Rossendorf*

More often than not, after having worked for some time on a problem related to dynamos or magnetic instabilities, I said to myself: I should have read Michael Proctor before! Actually, not many scientists have influenced magnetohydrodynamics so profoundly as he did. In a personally biased selection, I discuss some experimental and theoretical MHD topics which were strongly influenced by Michael Proctor's ideas. Those include:

1. The distinction between convective and absolute instabilities, which turned out to be essential for the experimental demonstration of the dynamo effect in Riga and the helical magnetorotational instability (MRI) in Dresden.
2. The Malkus-Proctor effect, as nicely illustrated by the saturation mechanism of the Riga dynamo,
3. Double-diffusive magnetic instabilities, such as buoyancy instabilities, but also helical and azimuthal MRI and Super-AMRI.
4. Spectral degeneracies of dynamo operators in diabolic or exceptional points, and their (putative) role for reversals of the geodynamo,
5. Highly nonlinear dynamo mechanisms, such as MRI dynamos and Tayler-Spruit dynamos.

Spatio-temporal Patterns in Inclined Layer Convection

Priya Subramanian, Oliver Brausch, Karen E. Daniels, Eberhard Bodenschatz, Tobias M. Schneider & Werner Pesch*
**University of Leeds*

Patterns driven by buoyancy (e.g., the Rayleigh-Bénard system) can be associated with a sequence of bifurcations of the uniform base state. Consequently, methods that exploit the linear instability such as weakly nonlinear analysis are employed to analyse them. In contrast, shear driven patterns (e.g. plane Couette flow) occur even when the associated basic state is linearly stable. Analysis of such subcritical patterns requires a fully nonlinear analysis and thus remains challenging. To investigate the formation of spatio-temporal patterns due to the interaction of buoyancy and a mean shear, we focus on the inclined layer convection (ILC) system. In the ILC cell, the fluid layer is inclined to the horizontal plane and subject to a temperature gradient and generates different patterns due to the interaction of buoyancy and shear. Three relevant parameters characterize this system: the ratio of momentum to thermal diffusivity (Prandtl number, Pr), the ratio of buoyancy to viscous forces (Rayleigh number, R) and the angle of inclination. At small angles of incline, the uniform base state becomes unstable to secondary instabilities in the form of buoyancy dominated longitudinal rolls. There exists a critical angle of incline, a codimension 2 point, above which shear driven transverse roll instabilities take over as the secondary instabilities. By varying the thermal driving and the inclination angle for a chosen Prandtl number fluid and computing the location of codimension 2 point, all secondary bifurcations and the resulting tertiary states, we characterize the weakly nonlinear behavior of ILC system. The computed secondary thresholds quantitatively match previous experimental observations.

What can Galloway and Proctor of various sizes teach us about dynamos at high Rm?

Steven Tobias, Fausto Cattaneo*
**University of Leeds*

The Galloway-Proctor flow is the king of kinematic dynamos. At fixed wavenumber it has a low critical Rm and is exceedingly quick. It also shows all the hallmarks of being fast. It is therefore the natural flow of choice to investigate dynamos at high Rm. Here we report on dynamo calculations and calculations of the EMF in a turbulent cascade of Galloway Proctor flows at high Rm and argue that mean field theory might not be quite as poorly as we thought it was.

Strong-field magnetoconvection
Geoff Vasil,*
**University of Sydney*

I will present a new nonlinear asymptotic reduced model of Rayleigh-Benard convection in the presence of a large background magnetic field. The talk will first discuss some aspects of the techniques and principles used to derive the model. After that, I will present nonlinear simulations of the resulting equations. The mathematical model displays an unusual type of nonlinear interactions. Qualitatively, the dynamics exist somewhere between chaotic pattern formation and two-dimensional turbulence.

The impact of magnetic topology on plasma dynamics
Anthony Yeates, Gunnar Hornig, Alexander Russell*
**Durham University*

How is a plasma's evolution affected by its global magnetic field structure? I will focus on trying to understand the self-organisation of turbulently relaxing plasma - a phenomenon observed in laboratory devices and hypothesised to occur in astrophysical plasmas such as stellar atmospheres. If these plasmas were perfect electrical conductors, their magnetic topology (linkage and connectivity of their magnetic field lines) would be perfectly frozen-in for all time. In reality, the turbulent flows lead to very sharp layers of electric current where even a very small resistivity allows for field-line reconnection. Nevertheless, it is well-known that the total magnetic helicity - an overall measure of the topology - remains a robust invariant. Thus the magnetic energy released during the relaxation may be limited by the conservation of total magnetic helicity. Our work goes further: we focus on the possible relevance of additional topological constraints beyond total magnetic helicity. In a turbulently relaxing plasma, we propose that the leading order behaviour is a re-organisation of field-line helicity, which in general will put additional constraints on the dynamics. If the region of turbulent reconnection is localised, one such constraint may be expressed as conservation of the topological degree of the magnetic field-line mapping.

The onset of low Prandtl number thermal convection in thin spherical shells
Ferran Garcia-Gonzale,*
**University of Amsterdam*

Convection is believed to occur in many geophysical and astrophysical objects such as planets and stars. In particular, compressible convection takes place in neutron stars and white dwarfs oceans that often exhibit thermonuclear explosions known as bursts when matter is accreted from a companion star. These oceans may be formed by very thin layers of Helium or Hydrogen which are subjected to the influence of strong temperature gradients and rotation. From nuclear physics theory the physical properties, such as kinematic viscosity or thermal conductivity, can be estimated giving rise to very low Prandtl and Ekman numbers. This parameter regime, in combination with very thin spherical shells, makes the study of convection extremely challenging, even in the incompressible case (Boussinesq).

In this study the onset of stress-free Boussinesq thermal convection with aspect ratio η =0.9, Prandtl numbers $Pr \in [10^{-4}, 10^{-1}]$, and Ekman numbers $E \in [10^{-5}, 10^{-3}]$ is considered. For a fixed E and by decreasing Pr from 0.1 a transition between spiralling columnar and equatorial modes, and a transition between equatorial and inertial modes are found. The latter modes are preferred at very low Pr. We study the dependence on Pr and E of both transitions to estimate the type of modes preferred at the bursting stars regime.

Poster Presentations

The dynamics of buoyant magnetic structures at the base of the solar convection zone
Abrar Ali, Lara Silvers, Oliver Kerr*
City, University of London

Motivated by a desire to greater understand dynamics inside the Sun, we have considered a fully compressible, three-dimensional MHD model to study the dynamics of buoyant magnetic structures at the base of the solar convection zone. Following on from Barker et al. (2012), here I present results for a variety of models aimed to investigate the competing effects of the overlying turbulent convection with buoyant magnetic structures in a compressible atmosphere. The numerical simulations of the governing equations reveals different behaviour of the magnetic field depending on the characteristics of the pumping and the preliminary implications of this is discussed.

Effects of Anisotropic Diffusivities on Onset of Rotating Magnetoconvection
Jozef Brestensky, Enrico Filippi, Tomas Soltis*
**Comenius University*

The turbulent stay of the Earth's outer core not only increases all diffusive coefficients, but it can cause their anisotropic properties. Therefore, the model of rotating magnetoconvection in horizontal plane layer rotating about vertical axis and permeated by homogeneous horizontal magnetic field, influenced by anisotropic diffusivities, viscosity and thermal diffusivity (Soltis and Brestensky, 2010), is advanced by considering the magnetic diffusivity as anisotropic, too (Filippi et al, 2017). The case of full anisotropy, i.e. with all anisotropic diffusive coefficients is compared with isotropic case of diffusive coefficients (Roberts and Jones, 2000) and with the case of partial anisotropy, i.e. mixed case of isotropic and anisotropic diffusive coefficients (viscosity and thermal diffusivity anisotropic and magnetic diffusivity isotropic).

Arising instabilities have a form of horizontal rolls inclined to the magnetic field direction with angle dependent on ratio of magnetic and Coriolis forces. Thus the modes of convection are stationary P, SO, SC and overstable OO, OC modes (Roberts and Jones, 2000; Soltis and Brestensky, 2010). The existence and preference of the modes is sensitive on all non-dimensional parameters, as well as on anisotropic parameter, the ratio of horizontal and vertical diffusivities. In two types of studied anisotropy, SA and BM, stratification anisotropy and Braginsky-Meytlis anisotropy (Braginsky and Meytlis, 1990; Soltis and Brestensky, 2010), respectively, a style of convection given by the onset of modes is more affected by anisotropic diffusivities in BM than in SA anisotropy. The differences between partial (Soltis and Brestensky, 2010) and full anisotropies (Filippi et al, 2017) are generally small.

On the effects of topography in rotating flows

Fabian Burmann, Jérõme André Roland Noir, Andrew Jackson*
**ETH Zürich*

Both, seismological studies and geodynamic arguments suggest that there is significant topography at the core mantle boundary (CMB). This leads to the question whether the topography of the CMB could influence the flow in the Earth's outer core?
As a preliminary experiment, we investigate the effects of bottom topography in the so-called Spin-Up, where motion of a contained fluid is created by a sudden increase of rotation rate. Experiments are performed in a cylindrical container mounted on a rotating table and quantitative results are obtained with particle image velocimetry. Several horizontal length scales of topography (λ) are investigated, ranging from cases where λ is much smaller than the lateral extend of the experiment (*R)* to cases where λ is a fraction of *R*. We find that there is an optimal lambda that creates maximum dissipation of kinetic energy. Depending on the length scale of the topography, kinetic energy is either dissipated in the boundary layer or in the bulk of the fluid. Two different phases of fluid motion are present: a starting flow in the form of solid rotation (phase I), which is later replaced by mesoscale vortices on the length scale of bottom topography (phase II).

Trapped inertial waves in vertically stratified, relativistic accretion disks

Janosz Dewberry, Henrik Latter*
**University of Cambridge*

High frequency quasi-periodic oscillations (HFQPO) seen in X-ray binary system light curves present a window into the intrinsic properties of stellar mass black holes and a test bed for general relativity. One potential explanation is that relativistic effects on the differential rotation of the black hole accretion disk create a resonant cavity in which so-called `gravito-inertial waves' (r-modes) might grow to observable amplitudes. However, local analyses predict that magnetic fields destroy the r-mode trapping region. We revisit this problem from a global context, deriving linearized equations describing a relativistic, magnetized accretion flow, and calculating normal modes both with and without density stratification away from the disk midplane. In the simple, unstratified approximation, increasing vertical magnetic field strength drives the r-modes toward the inner edge of the disk, supporting local theory's predictions of the magnetic destruction of the self-trapping region. However, the critical field strength for this destruction depends on the vertical wavenumber of the perturbations, a free parameter in the unstratified model. We explore the dependence of r-mode survival on density stratification and disk thickness more carefully through an approximate numerical analysis using truncated series expansions in appropriate basis functions.

Precessional-convectional instabilities in a spherical system

Leonardo Echeverria, Jerome Noir, Andrew Jackson, Philippe Marti*
**Institute of Geophysics, ETH Zurich*

Generally, the Earth’s dynamo is attributed to thermo-compositional convection, which is supported by numerical simulations in a range of parameters far from core conditions. Meanwhile, numerical studies (Tilgner, 2005; Wu and Roberts, 2009; Lin et al., 2016) have shown that precession is also a plausible forcing mechanism to drive a dynamo. In particular, Lin et al. (2016) have observed that large scale vortices (LSV) can favour the generation of large scale magnetic fields in the conducting region. Similar observations have been reported in thermal convection simulations (Guervilly et al., 2015) suggesting that LSV may play an important role in the dynamo process. Recent numerical simulations suggest that the coupled precession-convection forcing can enhance magnetic induction (Wei, 2016). In the present study we aim at investigating numerically in greater detail the coupled precession-convection dynamo starting with the purely hydrodynamical regime.

Dynamo action from a laminar non-linear flow in a precessing cylinder

Andre Giesecke, Tobias Vogt, Thomas Gundrum, Frank Stefani*
**HZDR*

Within the project DRESDYN (DREsden Sodium facility for DYNamo and thermohydraulic studies) a dynamo experiment is under development in which a precession driven flow of liquid sodium will be used to excite dynamo action. In my presentation I will address preparative numerical simulations and flow measurements conducted at a small model experiment filled with water. The results provide typical flow pattern and flow amplitudes in dependence of precession ratio and Reynolds number and are used for the setup of kinematic dynamo models in order to estimate whether the particular flow is able to drive a dynamo.

In the strongly non-linear regime the flow essentially consists of the directly forced Kelvin mode superimposed by standing inertial waves that are caused by nonlinear self-interaction of the forced mode whereas time-dependent contributions in terms of randomly distributed small-scale noise remain negligible. Most remarkable feature is the occurrence of a resonant-like axisymmetric mode around a precession ratio of $\Omega_{prec}/\Omega_{cyl} = 0.1$. Only the combination of this axisymmetric mode and the forced m=1 Kelvin mode is capable of driving a dynamo. The simulations yield a critical magnetic Reynolds number of Rm_c=430 which is well within the regime that will be achieved in the experiment. However, the occurrence of the axisymmetric mode slightly depends on the absolute rotation rate of the cylinder and future experiments are required to indicate whether this instability will persist at the extremely large Re that will be obtained in the large scale experiment.

Hydrodynamic Convection in Astrophysical Disks

Loren Held, Henrik Latter*
**University of Cambridge*

Convective instability in the plane vertical to the disk may play a key role in dwarf novae during their optically thick outburst phase. In particular, there has been some indication that an interplay between convection and the magnetorotational instability might enhance angular momentum transport. To understand the basic elements of convection in disks, we investigate the linear phase of the hydrodynamic convective instability, obtaining estimates on the growth rates both numerically, using one-dimensional spectral methods, as well as analytically using WKB methods. In addition, we perform local (shearing box), three-dimensional, hydrodynamic, fully compressible simulations with the conservative, finite-volume code PLUTO, both with and without explicit diffusion coefficients. We find that hydrodynamic convection can, in general, drive outward angular momentum transport, though the sign of angular momentum flux may be sensitive to the diffusivity of the numerical scheme. We also investigate forced convection by employing thermal relaxation and observe that this results in the formation of large coherent eddies and oscillatory convection.

Taylor state dynamos found by optimal control: axisymmetric examples

Andy Jackson, Kuan Li, Philip Livermore*
**ETH Zurich*

Taylor (1963) promulgated an inertia-free and viscous-free model as the asymptotic limit of Earth's dynamo. In this theoretical limit, the velocity and the magnetic field organize themselves in a special manner, such that, the Lorentz torque acting on a geostrophic cylinder has to tend to zero as the inertial force and the viscous force tend to zero.

We propose a new approach for solving this system based upon the concept of optimal control theory. In this approach, the Lorentz torque is treated as the target function to be minimized at each time step and we seek the optimal geostrophic flow, such that, the Lorentz torque remains arbitrarily small at the future time step. We demonstrate the success of this approach on illustrative models, namely 2D axisymmetric systems driven by prescribed α- and $\alpha\omega$-effects. Thus we will describe a number of dynamo solutions in the Taylor state.

Solving Secular 2D Eccentric Discs Exactly Using a Hamiltonian Formalism

Eliot Lynch, Gordon Ogilvie*
University of Cambridge

The fully nonlinear equations for 2D eccentric discs are a second order nonlinear ODE for eccentricity, with potentially an infinite number of terms containing unknowns. Using a new Hamiltonian formalism for eccentric discs and considering the problem in an inverse sense we obtain equations for the thermodynamic properties of the disc in terms of the specified disc geometry. These equations are not differential in nature as they only contain derivatives of known quantities. Thus exact solutions to the 2D secular disc equation can be obtain for generic Keplerian geometries.

Transitional dynamics in rotating low-Rm MHD turbulence

Ben McDermott, Peter Davidson*
University of Cambridge

We present direct numerical simulations of the evolution of the velocity field permeating from a ‘blob' of buoyancy for a range of Rossby numbers, under the influence of a low-Rm magnetic field. Of particular interest is the range Ro = 0-1, as it has been previously reported, for freely decaying rotating turbulence and for a localised vortical eddy, that an abrupt change in dynamics occurs at Ro = 0.4. For Ro < 0.4 linear inertial waves dominate the dynamics, forming the widely reported Taylor columns, whereas for Ro > 0.4 inertial forces quickly reorganise the flow. The aforementioned transition to the nonlinear regime is investigated in the frame of low-Rm magnetohydrodynamics (MHD) over a number of interaction parameters--- and comparisons will be made to the transition from dipolar to non-dipolar magnetic fields in convective geodynamo simulations. Indeed, the turbulent convection in Earth's outer core is operating at low Rossby number at all relevant scales, however this is not true of computationally feasible simulations to date; and the reversal mechanism in reversing numerical dynamos may be linked to the local Rossby number approaching order 1.

Rotating turbulent dynamos
Melissa Menu, Ludovic Petidemange*
**Ecole Normale Supérieure, Paris*

The dynamo effect is the most popular candidate to explain the non primordial magnetic fields of astrophysical objects (planets and stars).The magnetic field topology is thought to be affected by the physical conditions, and thus by the initial parameters of the system. Indeed, from the observations we can distinguish several behaviours, that we aim to reproduce in numerical simulations. For example, we tried to identify dynamical regimes coming from weak turbulence theory using a variety of simulations already performed, and by exploring new more turbulent regimes. Finally, our results allow a better understanding of the limits, and thus of the transitions, between each dynamo branch that we can obtain in our models.

Model with z-dependence for magnetic fields in the outer rings of galaxies
Evgeny Mikhaylov, Dmitry Sokoloff*
**Moscow State University*

Nowadays it is well known that some galaxies have regular magnetic fields of several μG. Their generation is described by dynamo mechanism that is based on joint action of alpha-effect (which characterizes turbulent motions of the interstellar medium) and differential rotation. Some of the galaxies have so-called outer rings, which are situated on some distance from the main part. The processes in the interstellar medium there are nearly the same. So the magnetic fields can be generated there, too. The main problem is that the outer rings can be quite thick, so we cannot use no-z model that describes the field generation in thin galaxy discs. We have constructed the model with z-dependence to study the field evolution. The main feature is that the field can have not only quadrupolar symmetry, but the dipolar mode can grow, too. We have studied numerically different regimes of the field generation for typical values of the outer rings parameters.

Alignment within dynamo theory
*Daniel Miller**
**University of Exeter*

Alignment of the fluid and magnetic field has been previously shown to play a role in the saturation of nonlinear dynamos at equipartition. In this poster I will show new results pertaining to nonlinear dynamos which saturate via an alignment mechanism.

Active region jets in the Solar atmosphere
Sargam Mulay, H. Mason*
University of Cambridge

Solar jet are the ubiquitous transient events in the solar atmosphere. They have been observed to originate from the edge of active regions and were named as active region jets. These events are mostly associated with sunspot regions and their signatures have been observed in H-alpha, at

UV/EUV and X-ray wavelengths. I'll be presenting multiwavelength observations obtained from the AIA/SDO, WIND/WAVES and RHESSI instruments. The active region jets and their associated phenomena such as nonthermal type III radio burst, hard x-ray emission and photospheric magnetic activity were studied. Plasma parameters, such as differential emission measure (DEM), peak temperature, plane-of-sky velocities, electron densities will be discussed using EUV imaging observations.

Fluid instabilities due to Inner Core nutation

Lardelli Nicolò, Philippe Marti, Andrew Jackson, Jerome Noir*
**ETH Zürich*

In planetary bodies having a fluid core, precession of the axis of rotation can generate large scale vortices capable of sustaining a dynamo effect (Lin et al., 2016).
We employ the QuICC simulation framework to study the effect of Inner Core (IC) nutation (phenomenon comparable to a precession of the mantle) on the fluid structures in the Outer Core (OC). In the linear regime ($R_o << 1$) we find a resonance ar ω=1, which corresponds to a Greenspan Q_{211} inertial mode.

Nonlinear State of the Fluctuation Dynamo

Amit Seta, Anvar Shukurov*
**Newcastle University*

Many astrophysical objects contain small-scale magnetic field that is generated by turbulence -- we call this a "fluctuation dynamo". Using three-dimensional numerical simulations, we measure the statistics and structural properties of the fluctuation dynamo in the kinematic and saturated states. We find that, whereas the velocity field has Gaussian statistics, the magnetic field is strongly non-Gaussian, with heavy tails that indicate spatial intermittency. The intermittency is more pronounced in the kinematic phase, but remains significant even in the saturated state. We compare the alignment of the magnetic field, current, and velocity in the kinematic and saturated states to suggest a possible saturation mechanism for the dynamo.

Growth of eccentricity in planet-disc interactions

Jean Teyssandier, Gordon Ogilvie*
**University of Cambridge*

The origin and wide distribution of eccentricities in planetary systems remains to be explained, in particular in the context of planet-disc interactions. In Teyssandier & Ogilvie (2016), we have formulated a set of linear equations that describe the behaviour of small eccentricities in a protoplanetary system consisting of a gaseous disc and a planet. Eccentricity propagates through the disc by means of pressure and self-gravity, and is exchanged with the planet via secular interactions. Excitation and damping of eccentricity can occur through Lindblad and corotation resonances, as well as viscosity. The linear theory predicts that eccentricity can grow within the disc's lifetime, both in the disc and in the planet. We compare this linear theory with hydrodynamical simulations for gap-opening planets. Above mass ratios of 0.003, the main features of eccentricity evolution in a disc are well captured by the linear theory (Teyssandier & Ogilvie, 2017).

The Influence of Turbulent Pumping and Turbulent Diffusion on Magnetic Buoyancy Instability

Daniela Weston, David Hughes*
**University of Leeds*

In the region of the solar tachocline, the mean field turbulent pumping and turbulent diffusion effects acting in the overlying convection zone create the potential for susceptibility to magnetic buoyancy instability. For a layer of field spanning this region, ie. subject to the z-dependent turbulent effects in its upper half, a basic state was sought by solving the induction equation for static equilibrium. In this case the induction equation is reduced to a second order linear ODE, which was solved numerically. Consideration was given to the forms of the turbulent effects and the boundary conditions for this equilibrium state. The resulting field profile was used as a self-consistent basic state and subjected to linear perturbations, and the most unstable mode was sought. The linear system was constructed numerically using a Chebyshev approach to ensure spectral accuracy.
In perturbing the layer, both interchange (2D) and 3D modes were considered, and the effect of changing the parameters and form of the turbulent pumping and turbulent diffusion effects was considered. The spatial wavenumbers in both horizontal directions were also varied, in order to compare stability for various parameter values. Existing stability criteria for magnetic buoyancy predict a region of parameter space in which only 3D modes are unstable, and seeking this regime given the turbulent effects is the subject of current and ongoing work.

Parameter optimization for surface flux transport models

Tim Whitbread, Joanne Mason*
University of Exeter

Accurate prediction of solar activity calls for precise calibration of solar cycle models. Consequently we aim to find optimal parameters for models which describe the physical processes on the solar surface. We use a genetic algorithm to optimize surface flux transport models using NSO magnetogram data for Cycle 23. This is applied to two models with distinct dimensionality and assimilation methods. The genetic algorithm searches for parameter sets that produce the best fit between observed and simulated butterfly diagrams, weighted by a latitude-dependent error structure which reflects uncertainty in observations. Due to the easily-adaptable nature of the 2D model, the optimization process is repeated for other cycles in order to analyse cycle-to-cycle variation of the optimal solution. We find that the ranges and optimal solutions for the various regimes are in reasonable agreement with results from the literature, both theoretical and observational. Differences between models appear to be important in deciding values for the diffusive and decay terms. In like fashion, differences in the behaviours of different solar cycles lead to contrasts in parameters defining the meridional flow and initial field strength.

Forced shear flows in polytropic atmospheres: large and small Péclet number regimes

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Complex mixing and magnetic field generation occur in stellar interiors particularly where there is a strong shear flow. To obtain a comprehensive understanding of these processes, it is necessary to study the complex dynamics in such shear regions. Due to current observational limitations, it is necessary to investigate the inevitable small scale dynamics via numerical calculations. Here, we examine direct numerical calculations of a local model of unstable shear flows in a compressible polytropic fluid, where we focus on determining how key parameters affect the global properties and characteristics of the resulting saturated turbulent phase. We consider the effect of varying both the Reynolds number and the Péclet number on the nonlinear evolution. Moreover, our main focus is to understand the global properties of the saturated phase, especially the spread of the turbulent region from an initially hyperbolic tangent velocity profile. Finally, including magnetic fields we investigate how magnetic fields interact with turbulent motion and whether such complex dynamics can generate and sustain large-scale magnetic fields. Here, we present some preliminary results on possible kinematic dynamo action in forced shear flows.