Thierry Alboussière (Laboratoire de Geologie de Lyon)

Compressible convection experiments, present and future

Using hypergravity in a centrifuge and xenon gas, we could run convection experiments where a significant adiabatic gradient develops. These experiments are also dominated by Coriolis effects and I will analyze some of their aspects. Temperatures (at 9 positions) and pressures (at 2 positions) are recorded. In all cases, we believe that the flow is quasi-geostrophic, from temperature correlations. The respective levels of temperature and pressure departures from the adiabatic profile and their contributions to entropy fluctuations is an issue regarding convection models. The flow consists mostly in a stationary part with smaller unsteady fluctuations. Concerning the convective heat flux, we find that two possible levels exist for some values of the imposed Rayleigh number. The upper branch corresponds to the classical Nusselt–Rayleigh relationship with an exponent 1/3 power law. Our experiments are restricted to large superadiabatic Rayleigh numbers, due to heat losses through side-walls. Future experiments should be designed to increase compressible effects and to address key questions: disentangle compressible and Coriolis effects, characterize hysteresis, investigate lower Rayleigh numbers.

Ann Almgren (Lawrence Berkeley National Laboratory)

Low Mach Number Modeling

Low Mach number equation sets approximate the equations of motion of a compressible fluid by filtering out the sound waves, which allows the system to evolve on the advective rather than the acoustic time scale. Depending on the degree of approximation, low Mach number models retain some subset of possible compressible effects. In this talk I will discuss low Mach number models for reacting and stratified flows arising in combustion, astrophysics and atmospheric modeling.

Evan Anders (University of Colorado, Boulder), Daniel Lecoanet, Benjamin P. Brown

Entropy Rain: Dilution and Compression of Turbulent Thermals in Stratified Domains

In low mass stars like the Sun, envelope convection may depend on cold downflows launched from the stellar surface to transport the stellar luminosity. These downflows can be modeled as dense, negatively buoyant atmospheric thermals, and we present an analytical theory describing their evolution with depth. We verify the theory with 3D, fully compressible simulations of laminar and turbulent low Mach number thermals in stratified atmospheres. Our results show that laminar dense thermals fall in two categories: a stalling regime in which the droplets slow down and expand, and a falling regime in which the droplets accelerate and shrink as they propagate downwards. In this talk, we present forthcoming first results on the evolution of turbulent thermals.

John Bell (Lawrence Berkeley National Laboratory)

Advection in Mesoscale Fluid Mechanics

At small scales, the Navier–Stokes equations traditionally used for fluid modeling break down and thermal fluctuations play an important role in the dynamics. At these scales, referred to as the mesoscale, advection can introduce structure into the solution, arising from correlation between fluctuations in different fields. To capture the effect of fluctuations, Landau and Lifshitz proposed a modified version of the Navier–Stokes equations, referred to as the fluctuating hydrodynamics (FHD) that incorporates stochastic flux terms designed to incorporate the effect of fluctuations. These stochastic fluxes are constructed so that the FHD equations are consistent with equilibrium fluctuations from statistical mechanics. Here we describe the development and analysis of finite-volume methods for solving the equations of fluctuating hydrodynamics for miscible fluid mixtures. We present numerical results that validate the methodology and illustrate how fluctuations impact systems out of equilibrium.

Andrew Clarke (University of Leeds)

Parallel in time integration of dynamo simulations

The precise mechanisms responsible for the natural dynamos in the Earth and Sun are still not fully understood. Numerical simulations which couple the flow of a conducting fluid with magnetic effects, using the equations of magnetohydrodynamics (MHD), are used to investigate the dynamo effect. These simulations are extremely computationally intensive, and are carried out in parameter regimes many orders of magnitude away from real conditions.

Parallelization in space is a common strategy to speed up simulations on high performance computers, but eventually a scaling limit is reached due to increasing overheads from communication. Additional directions of parallelization are desirable to utilise the high number of processor cores available in current and future massively parallel high-performance computing systems.

Parallel-in-time methods can deliver speed up in addition to that offered by spatial partitioning but have not yet been applied to dynamo simulations. We investigate the ability of parallel in time methods to speed up dynamo simulations in two different areas. First, we have investigated the feasibility of using the parallel-in-time algorithm Parareal to speed up initial value problem simulations of the kinematic dynamo — a simplification of the dynamo problem which concentrates on the magnetic field effects. Secondly, we investigate the ability of this technique to speed up simulations of Rayleigh–Bénard convection, a simplified model of the types of flow responsible for dynamo behaviour.

The pseudo-spectral python based code Dedalus is used in numerical simulations. Results show that both the Roberts and Galloway–Proctor kinematic dynamos can benefit from extra speed up using parallel in space and time methods, in addition to speed up from parallel in space. Results for the Galloway–Proctor flow are promising, with speed ups of 300 found with 1600 cores. Early results for Rayleigh–Bénard convection will be presented.

Robert Cooper (Newcastle University)

Subcritical Cartesian convection driven dynamos at low Ekman number

We study Cartesian, Boussinesq convection driven dynamos at rapid rotation (low Ekman numbers), focussing on subcritical dynamo action. We will present recent results where we aim to explore the parameter space at Rayleigh numbers below the onset of convection. Supercritical dynamo action is able to generate a strong, large-scale magnetic field which we are then able to extend subcritically, sustaining dynamo action below convective onset. We show that at more rapid rotation we are able to sustain a dynamo further into the subcritical regime.

Tim Cunningham (University of Warwick)

Convective overshoot in white dwarf atmospheres

There exist many evolved planetary systems around white dwarfs and, given that this is the likely fate of most planetary systems (including our own), the study of such configurations continues to be an active field of research. For the atmospheres of white dwarfs with effective temperatures ¡ 15000 K the process of atmospheric energy transfer becomes dominated by convection, rather than radiation, keeping metals suspended in the atmosphere for much longer times. Conventionally, calculations of the mixed mass of accreted metals are performed using the 1D mixing length theory, but recent studies have highlighted the necessity of including convective overshoot. This non-linear boundary effect, which requires multi-dimensional simulations to be properly characterised, can significantly increase the inferred mixed mass.

Using the 3D radiation-hydrodynamics code CO5BOLD, in a grid-based implementation, we are modelling the convective behaviour of hydrogen atmosphere white dwarfs. In particular, we are probing the temperature range 11400K – 18000K where convection is existent, yet confined to a region small enough to allow modelling of the full vertical extent of the convective and overshoot layers. We will present the first 3D simulations of degenerate stars with passive scalar particles that provide a statistical characterisation of the macroscopic diffusion of metals in the overshoot layers below the convective zone. Our results suggest that macroscopic diffusion, driven by convective overshoot, decays over at least 2.5 pressure scale heights beneath the unstable layers, leading to much larger mixed masses. The presentation will also consider the implications this has for the inferred accretion rates, masses and compositions of evolved planetary systems.

Laura Currie (University of Exeter)

Stratification effects in anelastic convection

Convection is important for transporting the heat generated in stars outwards. Coupled with rotation, it is also thought to play an important role in the generation of magnetic fields in stars. Furthermore, stellar interiors can by strongly stratified, (e.g., the Sun's convection zone contains about 14 density scale heights) and so understanding the interaction of compressibility effects and convection is key to describing many astrophysical systems. In this talk, I will consider the effects of stratification in convection through a series of two- and three-dimensional numerical simulations in a Cartesian domain under the anelastic approximation. In particular, I will explore the differences from the incompressible (Boussinesq) system that arise due to stratification. One key result from existing theory is that, for strongly stratified systems, the rate of dissipative heating can exceed the luminosity carried by convection. I will demonstrate this to indeed be the case in our simulations, and will consider the potential implications for the modelling of stellar interiors where modern standard evolutionary codes do not currently allow for dissipative heating. Time permitting, I will also show the flows generated in some of our simulations and discuss their potential suitability as candidates to sustain a large-scale magnetic field through dynamo action.

Craig Duguid (University of Leeds)

Tidal flows and convection: Frequency dependence of the effective viscosity and evidence for anti-dissipation

The fluid dynamical mechanisms responsible for tidal dissipation in giant planets and stars remain poorly understood. One key mechanism is the interaction between tidal flows and turbulent convection. This is thought to act as an effective viscosity in damping the equilibrium tide, but the efficiency of this mechanism is still a matter of much debate.

Using hydrodynamical simulations we investigate the dissipation of the equilibrium tide as a result of its interaction with convection. We model the large-scale tidal flow as an oscillatory background shear flow inside a small patch of convection zone. We simulate Rayleigh–Bénard convection in this Cartesian model and explore how the effective viscosity of the turbulence depends on the tidal (shear) frequency.

I will present the results from our simulations determining the effective viscosity, and its dependence on tidal frequency. I will focus on the scaling of the effective viscosity with tidal frequency in the limit of large tidal frequencies. I will also demonstrate, using both analytical theory and numerical simulations, that negative effective viscosities are possible in this system. Finally, the implications of our results for the orbital decay of hot Jupiters will be discussed.

Philipp Edelmann (Newcastle University)

Core convection and internal gravity waves in massive stars

Massive stars with convective cores and radiative envelopes excite internal gravity waves (IGWs) at the convective-radiative interface. These waves are amplified as they propagate towards the surface of the star, which can lead to non-linear effects, such as wave breaking. This deposits angular momentum and causes shear layers to form in the radiation zone. Additionally, signatures of IGWs from the core can be found in recent asteroseismological observations.

I will show our group's recent 3D simulation of core convection and a large part of the envelope, which self-consistently model wave generation and propagation. Important results are the spectrum of waves generated and the shape of the spectrum close to the surface of the star, which relates to observables. I will also compare the results of these pseudo-spectral simulations in the anelastic approximation with another simulations performed using a finite-volume, fully compressible code, in particular looking at the effect of artificial viscosity.

Colin Hardy (University of Leeds)

Constraining the magnetic field throughout Earth's core

Vigorous, rotationally constrained, buoyant convection of the molten iron within the Earth's outer core is responsible for sustaining the Earth's magnetic field through the mechanism known as the geodynamo. The fluid motion driving the geodynamo is governed by the MHD equations, and significantly, rotational forces are dominant over inertial and viscous forces, which in terms of dimensionless numbers means that the Ekman and Rossby numbers are very small. The extreme nature of these values leads to a problem for numerical simulations, since it means that they are required to resolve a large contrast of both spatial and temporal scales, making it too computationally expensive to be feasible for the correct parameter regime. There is an alternative approach proposed by Taylor in 1963, of an inertia-free and viscosity-free model as the asymptotic limit of Earth's dynamo. In this theoretical limit of a magnetostrophic balance, a certain necessary condition, now well known as Taylor's constraint, must hold.

Recently observed seismic velocity perturbations provide significant evidence for the existence of a layer of stably stratified fluid at the top of Earth's outer core. In this work we determine how the structure of the geomagnetic field is constrained within such a stratified layer. We demonstrate that a more strict constraint arises from the generalisation of Taylor's constraint within a stably stratified fluid.

We have developed a method for constructing a magnetic field which is both compatible with geomagnetic observations and satisfies this constraint. We present solutions of this system, which represent a model for the magnetic field throughout the whole core including a stratified layer immediately beneath the CMB. We discuss how such magnetic fields can be used as part of a background state to model waves and other dynamics within the stratified layer.

Loren Everett Held (University of Cambridge)

Hydrodynamic Convection in Astrophysical Disks

The prevalence and consequences of convection perpendicular to the plane of accretion disks have been discussed for several decades. Recent simulations combining convection and the magnetorotational instability have given fresh impetus to the debate, as the interplay of the two processes can enhance angular momentum transport, at least in the optically thick outburst stage of dwarf novae. In this talk, we seek to isolate and understand the most generic features of disk convection, and so undertake its study in purely hydrodynamical models. First, we investigate the linear phase of the instability, obtaining estimates of the growth rates both semi-analytically, using one-dimensional spectral computations, and analytically, using WKBJ methods. Next, we perform three-dimensional, vertically stratified, shearing box 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, a result that we confirm with ATHENA, an alternative finite-volume code. Moreover, we establish that the sign of the angular momentum flux is sensitive to the diffusivity of the numerical scheme. Finally, in sustained convection, whereby the system is continuously forced to an unstable state, we observe the formation of various coherent structures, including large-scale and oscillatory convective cells, zonal flows, and small vortices.

Alex Hindle (Newcastle University)

Archetypically, hot Jupiters (Jupiter-sized exoplanets in close proximity to their host star) are observed to have eastward (prograde) equatorial jets. Such observations are consistent with hydrodynamic theory and simulations, which predict the eastward jets result from an interaction between mean azimuthal flows and the system's resonant, planetary scale, standing, equatorial shallow-water waves. However, westward equatorial winds have now been inferred for three hot Jupiters: HAT-P-7b, CoRoT-2b and Kepler-76b. Such observations could be the result of a number of physical phenomena such as cloud asymmetries, asynchronous rotation, or magnetic fields. For the hotter hot Jupiters magnetic fields are an obvious candidate, though the actual mechanism remains poorly understood. We present a simplified approach to understanding magnetically driven wind reversals, using a shallow-water magnetohydrodynamic model to investigate the phenomenon. We show that the simplified model can capture the appropriate physics and link the reversals to a modification in the structure of the system's planetary scale, standing, equatorial shallow-water waves. The findings of our investigation lead to a minimum magnetic field criterion for the emergence of magnetically driven reversals. We apply this to the hot Jupiter parameter space and find (1) the magnetic wave-driven reversal mechanism provides an explanation for wind reversals on HAT-P-7b; (2) other physical phenomena provide more plausible explanations for wind reversals on CoRoT-2b; (3) we find that wind variations caused by the magnetically driven wind reversals process would be expected on a number of the hottest hot Jupiters, which we identify for observational comparison. (DOI for associated publication: `https://doi.org/10.3847/2041-8213/ab05dd`).

Kumiko Hori (Kobe University/University of Leeds)

Anelastic torsional oscillations in Jupiter's metallic hydrogen region

The metallic hydrogen regions in deep interiors of gas planets hosts the dynamo action, and possibly the rapid dynamics including waves. We explore these waves by using Jovian anelastic dynamo simulations. Our models demonstrated axisymmetric fluctuations travelling perpendicular to the rotation axis on timescale of at least several years: they were identified as anelastic torsional Alfvn waves. Being excited by the more vigorous convection in the outer part of the dynamo region, they can propagate both inwards and outwards. When being reflected at a transition to the molecular region, they can form standing waves. Identifying such reflections in observational data could determine the depth at which the metallic region effectively begins. Our models showed these internal disturbances could give rise to variations in the planet's rotation period and in the zonal flows above the the metallic region.

Chris Jones (University of Leeds)

Fully developed anelastic convection in a plane layer

At high Rayleigh number, anelastic convection between no-slip plane parallel boundaries develops a well-mixed isentropic interior with thermal and viscous boundary layers close to the bounding surfaces. Unlike the Boussinesq case, the top and bottom boundary layers are very different, particularly when the layer contains many density scale heights. How the structure of these different boundary layers is determined will be discussed. Although the entropy is well-mixed, the horizontally averaged temperature gradient in the bulk interior can be subadiabatic, By considering the boundary layers and the entropy production equation, we show how scaling laws for the Nusselt number and Reynolds number can be derived in terms of the Rayleigh number, Prandtl number and boundary temperature ratio.

Petri Käpylä (Georg-August-University Göttingen)

Overshooting in simulations of compressible convection

Convective mixing in stars has important consequences, for example, in early and late phases of stellar evolution and for the diffusion of light elements. Thus it is of great interest to be able to predict where effective convective mixing occurs. The greatest uncertainty in this respect is the amount of overshooting from convection zones (CZ) to adjacent radiative layers.

I will describe a set of numerical experiments of fully compressible 3D convection with unstably and stably stratified layers wherefrom the scaling of overshooting as a function of the input energy flux is studied. The simulations cover almost four orders of magnitude in the imposed flux. Great care was to taken to isolate the effect of the flux alone and to eliminate the effects of varying degree of turbulence, supercriticality of convection, and changing Prandtl number.

The current results suggest that the scaling of overshooting with flux is much shallower than suggested by earlier analytic and numerical work. The results of the latter are likely to be explained by the sensitivity of overshooting to the effective Prandtl number. Extrapolating the results to the Sun suggest an overshooting depth of 0.2 pressure scale heights at the base of the solar CZ. This, however, must be considered as an upper limit due to the fact that the lower part of the solar CZ is strongly influenced by rotation and magnetic fields which were omitted in the present study.

Daniel Lecoanet (Princeton University)

In nature, convective flows are often bounded by stably stratified fluid, rather than impenetrable walls. I will describe a model for such a system using a nonlinear equation of state. I will present a series of simulations of rapidly rotating convection adjacent to stable stratification. As in simulations without the stable region, the convection self-organizes into a large-scale vortex. However, the stable stratification can stall the inverse cascade, and limit the horizontal extent of these vortices. I will present a simple model of the vortex flow within the stratified layer, which predicts the horizontal size of the large-scale vortices.

Stephen Mason (Newcastle University)

Rotating Spherical Magnetoconvection

The geomagnetic field is thought to exert a strong influence on the dynamics of the outer core. Modelling the magnetically-dominated convection regime in self-sustained dynamos is challenging numerically as it requires low Ekman numbers or large magnetic Prandtl numbers. Here we will study this regime through the use of magnetoconvection simulations in a rotating spherical shell, in which an imposed uniform axial field interacts with convective flows to induce an additional field. Gradually increasing the strength of the imposed field allows us to determine the conditions under which the magnetic forces affect the dynamics of the flow. We will show how the flow structures and heat transport are modified in the presence of the field.

Ben McDermott (University of Cambridge)

The helicity characteristics and induced emf of magnetic-Coriolis wave packets

The importance of inertial waves for the maintenance of quasi-geostrophy in planetary cores has recently received much attention. Indeed, low frequency inertial packets are spontaneously emitted from a buoyant source in a rapidly rotating frame, and progress to form elongated helical structures aligned with the rotation axis. However, in a planetary core we expect to find a dynamic large-scale magnetic field. The magnetic field will modify inertial wave packets, generally reducing their group velocity, and modifying their helicity characteristics. We present numerical simulations with a mean magnetic field in a rapidly rotating frame, in which the flow is forced by a layer of buoyant anomalies. We assess the effect of a strong magnetic field on: i. the morphology of magnetic-Coriolis wave packets; ii. the kinetic, magnetic and cross helicity transport by the waves; iii. the induced emf (and alpha-effect) with the potential to drive a large-scale dynamo. Implications for dynamo simulations and planetary cores are discussed.

Krzysztof Mizerski (Institute of Geophysics Polish Academy of Sciences)

Fully developed anelastic convection with viscous dissipation in the bulk

The properties of fully developed compressible convection substantially differ from the Boussinesq case. The main reason is that the thermal and kinetic energies are comparable in the compressible case thus the work of the buoyancy force and the viscous heating are non-negligible compared to the total heat flux in the system. We study here the influence of density stratification on the Rayleigh (and Prandtl) number dependence of the Nusselt and top and bottom Reynolds numbers in anelastic convection and we focus on the case, when the viscous dissipation takes place predominantly in the bulk. It is reported, that the dynamics of the top and bottom boundary layers differs significantly. The top boundary layer is typically thicker and the entropy jump across it is larger than in case of the bottom boundary layer. The top boundary layer is also more prone to instability than the bottom one, since the local Reynolds number based on the boundary layer thickness and the convective velocity is significantly larger in the former case.

The ratios of the thicknesses of the top to bottom boundary layers, likewise the temperature and entropy jumps across them are calculated. The relation between the maximal top and bottom velocities of large-scale convection rolls (the 'wind of turbulence') is obtained. This allows to precisely estimate the mean superadiabatic heat flux in the system, which strongly depends on height due to the effect of the viscous heating and the work of buoyancy.

Miroslav Mocak (NESS KDC)

Analysis framework for 3D multi-fluid compressible hydrodynamic simulations

Turbulence is one of the most fundamental processes in stars and before taking into account binarity, magnetism or rotation of a star to explain observations, we should understand stellar turbulence well first. It is arguably the greatest weakness in the modern theory of stellar evolution, which is mostly derived from 1D calculations approximating dynamic turbulent processes by simplified theories. In reality, turbulent flows are multidimensional, compressible and driven by non-linear terms of the hydrodynamic Navier–Stokes equations.

We analyze 3D multi-fluid hydrodynamic simulation of oxygen burning convective shell in a massive star within context of the Reynolds-Averaged Navier–Stokes (RANS) approach. It is a unique way of learning about turbulence based on budget analysis of hydrodynamic equations averaged in space and time, by which complexity of every term is reduced to a one-dimensional mean field.

Using this methodology, we derived RANS evolution equations for transport/flux/variance of mass, momenta, kinetic/internal/total energy, temperature, enthalpy, pressure and composition densities and implemented them to analysis framework, that we call rans(eXtreme) or ransX for short. It

is free to download and test to anyone from github repository located at
`https://github.com/mmicromegas/ransX`

We find that compressibility and non-local effects play important roles in core convection of stars.

Janet Peifer (University of Leeds)

Numerical and experimental modeling of rotating convection with two phases

In a world where climate change is causing increases in extreme weather, accurate weather prediction is a primary concern for people and governments hoping to adapt to changing conditions. Numerical Weather Prediction (NWP) is a powerful field for predicting and modeling atmospheric systems. Further development of NWP techniques for large weather systems is a relevant venture in the field of atmospheric modelling. One such improvement could be made by advancing the ability to model phase change during large-scale, rapidly rotating convection. In order to compare numerical models with observations, the phase change between vapor and solid will be modeled numerically and experimentally. Experimentally, this can be achieved using iodine gas in a convective cell.

Initially, a fast autoconversion and rain evaporation model will be numerically solved and compared with the full partial differential equations. Comparisons between the full model and a reduced model valid for rapid rotation will be carried out utilizing Dedalus Project spectral method software (`dedalus-project.org`). This model is then adjusted to accurately model vapor and solids in order to compare with experiments. The resulting model will also be formulated in the rapidly rotating limit.

The experimental component of this investigation will involve a rotating canister of iodine gas heated from below and cooled from above. Iodine's ability to easily desublimate is utilized to replicate an idealized behavior of water in the atmosphere. Initial results from these experiments are compared to initial numerical models of the same system.

Christina Pontin (University of Leeds)

Wave propagation and tidal dissipation in giant planets containing regions of layered semi-convection

Observations of the satellites of Jupiter and Saturn indicate higher tidal dissipation rates in these planets than standard theoretical models predict (Lainey et al. 2009, 2012, 2017), which suggests there is an additional mechanism for tidal dissipation. The presence of heavy element gradients in giant planet interiors, consistent with recent gravity field measurements from Juno (Wahl et al. 2017), can lead to regions where ordinary convection is inhibited but double-diffusive convection occurs. This can lead to a nearly discontinuous staircase-like density structure, consisting of well-mixed convective layers separated by infinitesimally thin interfaces. This staircase structure can strongly modify the propagation of internal waves, and potentially also lead to enhanced tidal dissipation.

I will present calculations to explore how internal wave propagation and tidal dissipation in a giant planet are affected by regions containing double-diffusive staircases. The model adopted here is a Boussinesq system in spherical geometry, which extends previous work in the Cartesian limit (Belyaev et al. 2015, Sutherland 2016, Andr et al. 2017). I will first present the properties of the free modes of a density staircase and show there are bands of enhanced wave transmission dependent on the staircase properties. Finally, I will present calculations to explore the resulting tidal dissipation.

Laura Scott (Keele University)

Convective boundary structure, evolution and mixing: New insight from 3D simulations

Convection is a long standing and problem in Astrophysics. The widely-used mixing-length theory fails particularly at convective boundaries. Current computing resources now enable us to undertake detailed 3D hydrodynamic simulations to gain precious insight into convective boundaries. In this talk, I will present the results of 3D hydro ILES simulations of convective boundaries for a carbon-burning shell in massive stars (Cristini et al. 2017, 2019). I will then present our RA-ILES analysis framework of these 3D hydro simulations and the implications of our results for the convective boundary structure, evolution and mixing (Arnett et al. 2018, 2019). Finally, I will present initial results of implementing these 3D-guided into 1D stellar evolution models.

Radostin Simitev (University of Glasgow)

Baroclinically-driven flows and dynamo action in rotating spherical fluid shells

The dynamics of stably stratified stellar radiative zones is of considerable interest due to the availability of increasingly detailed observations of Solar and stellar interiors. This article reports the first non-axisymmetric and time-dependent simulations of flows of anelastic fluids driven by baroclinic torques in stably stratified rotating spherical shells — a system serving as an elemental model of a stellar radiative zone. With increasing baroclinicity a sequence of bifurcations from simpler to more complex flows is found in which some of the available symmetries of the problem are broken subsequently. The poloidal component of the flow grows relative to the dominant toroidal component with increasing baroclinicity. The possibility of magnetic field generation thus arises and this paper proceeds to provide some indications for self-sustained dynamo action in baroclinically-driven flows. We speculate that magnetic fields in stably stratified stellar interiors are thus not necessarily of fossil origin as it is often assumed.

Jonathan Thurgood (Newcastle University)

A Hamiltonian approach to low mach number flow

Yue-Kin Tsang (University of Leeds)

Spectra of magnetic energy and secular variation in a dynamo model of Jupiter

Jupiter is mainly composed of hydrogen and helium. Physical properties, such as density, temperature and pressure, of the hydrogen–helium mixture vary over several order of magnitudes from the surface to the interior of the planet. Beyond a certain depth, temperature and pressure become high enough that hydrogen becomes metallic and the convection of this electrically conducting liquid hydrogen generates the Jovian magnetic field through dynamo action. While we cannot make direct observation of the dynamo inside Jupiter, it is possible to deduce some of its properties from surface measurement. Here, we model Jupiter's dynamo using a set of anelastic magnetohydrodynamics equation. We calculate the magnetic energy spectrum and the secular variation spectrum in our model and discuss what these spectra can tell us about the characteristics of the dynamo such as how deep it is located and how it interacts with the zonal wind.

Dimitar Vlaykov (University of Exeter)

Statistics of convective boundary mixing in sun-like stellar interiors

The process of convective penetration or overshooting, the penetration of convective motions into stably stratified layers significantly affects critical stellar processes such as angular moment transport and chemical mixing. The convective boundary layer at which this occurs is characterised by strongly intermittent dynamics — the most vigorous penetrating flows occur with abnormally high frequency. As a result traditional low-order statistics provide a poor description of convective overshooting and its effects, in particular chemical mixing and wave excitation.

This study shall present some of the challenges in the characterisation of convective structures at the interface between the stably-stratified radiative core and the turbulently convective envelope in sun-like stars. We focus on the dependence on basic stellar properties like the rotation rate and the depth of the convection and radiative layers.

The analysis is performed using the MUltidimensional Stellar Implicit Code (MUSIC). The code solves the full compressible Euler equations closed with a realistic equation of state and thus is able to follow the generation and propagation of internal waves in the radiative region.

Fryderyk Wilczynski (University of Leeds)

Convective motions in the scrape-off layer of magnetically confined plasmas

In magnetic confinement devices, the boundary turbulence is characterized by intermittent ejection of coherent filamentary structures. These filaments transport plasma from the well-confined core region, through the Scrape-Off Layer (SOL), towards the material surfaces. This results in increased plasma-wall interaction, which has the potential to damage plasma-facing components and shorten the lifetime of the device. It is therefore essential to develop a full understanding of the mechanisms behind the transport in the edge of the plasma.

Study of the formation and expulsion of filaments requires consideration of both the core and the SOL region. The two regions exhibit distinct dynamics parallel to the magnetic field. In the core, field lines are considered periodic in the parallel direction, while in the SOL the field lines end with a Debye sheath at a material surface. The presence of the sheath provides a sink for plasma particles and energy. Mathematically, this is represented by inclusion of parallel loss terms in the SOL region. In this contribution, we study the stability of the boundary plasma by considering a two dimensional interchange model that includes a simple description of open and closed field line regions. Although such two-region models have become fairly standard in numerical modelling of filament generation, their linear stability properties have not been explored.

The fundamental mechanism of interchange drive in edge plasma has been compared to that of buoyancy drive in neutral fluids, with reference to Rayleigh–Bénard convection in particular. Indeed, simple two-region core–SOL model can be viewed as a modified two-layer convection problem, where the core region in unstably stratified and the SOL is stably stratified. Initial results from the linear stability analysis of this system reveal a variety of distinct behaviour at the onset of instability.

Michael Zingale (Stony Brook University)

MAESTROeX: applications and future developments

I will describe some of the current and future applications of the MAESTROeX low Mach number stellar hydrodynamics code, including applications to convection in white dwarfs and massive stars. I will also describe the open development model of MAESTROeX, and discuss new features planned or under development, including GPU offloading, tighter coupling of hydrodynamics and reactions, and higher-order methods.