UK MHD 2023 (Wed 17th–Fri 19th May)
University of Leeds
Abstract Booklet

Wayne Arter (UKAEA)
"Further applications of the Lie-Taylor theory to HD+MHD" **Wed 17th 15.30-17.10: Third session**

Description of recent work on applications of the Lie-Taylor theory developed in the cited reference. Arter W. 2017 Beyond linear fields: the Lie–Taylor expansion. Proc. R. Soc. A 473: 20160525. http://dx.doi.org/10.1098/rspa.2016.0525.

Nils de Vries (University of Leeds)
"Tidal dissipation in Hot Jupiters due to non-linear interactions of the elliptical instability and convection" **Thur 18th 09.30-11.00: Fourth session**

Tidal dissipation in star-planet systems can occur through a myriad of mechanisms, one of which is the elliptical instability. This instability acts on elliptically deformed equilibrium tidal flows in rotating fluid planets and stars, and excites inertial waves in convective regions if the dimensionless tidal amplitude (ϵ) is sufficiently large. I will present results of its interaction with turbulent convection, and attempt to constrain the contributions of both elliptical instability and convection to tidal dissipation. We find that tidal dissipation resulting from bursts of elliptical instability, when it operates, is consistent with scaling as ϵ^3, as in prior simulations without convection. Convective motions also act as an effective viscosity on large-scale tidal flows, resulting in continuous tidal dissipation (scaling as ϵ^2). We derive scaling laws for the effective viscosity using (rotating) mixing-length theory, and find that they predict the turbulent quantities found in our simulations very well. In addition, we examine the reduction of the effective viscosity for fast tides, which we observe to scale with tidal frequency (ω) as ω^{-2}. We evaluate our scaling laws using interior models of Hot Jupiters computed with MESA. We conclude that rotation reduces convective length scales, velocities and effective viscosities (though not in the fast tides regime). We estimate that elliptical instability is efficient for the shortest-period Hot Jupiters, and that effective viscosity of turbulent convection is negligible in giant planets compared with inertial waves.

Craig Duguid (Newcastle University)
"Shear-driven magnetic buoyancy in the solar tachocline: The mean electromotive force due to rotation" **Poster**

Context: In the pioneering work of Parker (1955) the author set out the process by which the Sun could self-sustain its magnetic field (the alpha-omega dynamo). However, recent work (Cattaneo and Hughes 2006, Favier and Bushby 2011) has found that convective turbulence is inefficient at producing a large-scale poloidal field in this system. Aims: Our aim is to return to Parkers original ideas and explore a system which has an omega-effect, from a tachocline-like shear flow, and assess an alpha-effect due to the interaction of rotation and magnetic buoyancy. We wish to assess the ability for this interaction to produce an electromotive force (EMF) which can be related to an alpha-effect. Methods: Using numerical simulations, we explore a fully compressible magnetohydrodynamic system with an imposed vertical field and a tachocline-like vertical shear within a Cartesian. To extend upon Silvers (2009) we introduce rotation into the system and compute components of the EMF. Results: By comparing the non-rotating and rotating systems we find that the component of the EMF which acts on the large-scale poloidal field can have a systematic structure providing the rotation rate is rapid enough. These results suggest that the combination of magnetic buoyancy and rotation has the potential to produce large scale poloidal field from a shear induced toroidal field.

Robert Dymott (University of Leeds)
"Linear and nonlinear properties of the Goldreich-Schubert-Fricke instability in stellar interiors with arbitrary local radial and latitudinal differential rotation" **Poster**

Magnetohydrodynamical instabilities play an extremely important role in the development and dynamics of many astrophysical systems. The turbulence resulting from the GSF instability in particular has been thought to contribute to redistribution of angular momentum and chemical composition in stars. In our local Boussinesq model, we investigate how arbitrary differential rotation profiles effect the instability by introducing a new parameter ϕ, which governs the orientation of our shear locally. Along with the linear instability we explore the nonlinear hydrodynamical evolution in three dimensions using a modified shearing box. Interestingly we found our model exhibits both the diffusive GSF instability, and a non-diffusive instability that occurs when the Solberg-Hoiland criteria are violated. We observe the nonlinear development of strong zonal jets ("layering" in the angular momentum) with a preferred orientation in both cases, which can considerably enhance turbulent transport. We also show that the final levels of angular momentum transport in the system depend directly on our choice of ϕ. By exploring the dependence on box size, we find the transport properties of the GSF instability to be largely insensitive to this, implying we can meaningfully extrapolate our results to stars.

Jian Fang (STFC Daresbury Laboratory)
"A High-Order Solver for Turbulence, MHD and Particles" **Thur 18th 14.00-16.00: Sixth session**

In this talk, we discuss the recent development of particle tracking and MHD functionalities in the computational fluid dynamics solver, Xcompact3D, which is currently being used to study turbulence. By utilizing the high accuracy nature of the high-order finite-difference methods and the excellent performance of Xcompact3D on modern high-performance computing systems, we expect to contribute a high-fidelity simulation capability to nuclear and accelerator research communities, opening interdisciplinary connections and new research opportunities.

Lucas Gosling (University of Leeds), Adrian Barker & David Hughes
"Variably-Diffusive Magnetic Buoyancy in the Anelastic Regime" **Poster**

Magnetic buoyancy is the ability for magnetic field gradients to reduce the density of electrically-conducting fluids, making them buoyant in a relatively weakly-magnetised atmosphere. The instability has been well-scrutinised in the Boussinesq regime, but the understanding in the more-general anelastic regime is limited. Here we present the governing equations of magnetic buoyancy in a weak field-gradient ($d/H_B \ll 1$) anelastic atmosphere, permitting not only diffusive effects but the consequences of the spatial variability of diffusion also.

Luke Gostelow (University of Leeds)
"Shear Instabilities in QG Shallow Water MHD" **Fri 19th 09.30-11.00: Seventh session**

It was only twenty years ago that the rotating shallow-water equations were extended to include magnetic fields. This is a quasi-2D representation of density-stratified incompressible MHD and so this, where it excludes none of the relevant effects, will greatly improve our ability to simulate and predict the dynamics of e.g. the Solar tachocline. In the rapidly rotating limit, we can obtain an analogue to the hydrodynamic quasi-geostrophic equations which have been used to model large-scale flows in the terrestrial atmosphere and oceans. Here we investigate the effects of rotation, stratification, and a magnetic field on the linear instability of a zonal flow, which can be thought of as approximating the Solar differential rotation. We derive the necessary conditions for the presence of unstable modes and bound the phase speed and growth rate of these instabilities. We will then consider the vortex sheet profile for which analytic solutions can be derived and can be shown, in certain cases, to be the long-wave limit of disturbances to smooth profiles which we will verify numerically for the hyperbolic tangent profile. Numerical simulations using a Fourier-Chebyshev method show how these linear modes dominate the early phase of the nonlinear evolution.

S.D.Griffiths (University of Leeds) , A.D.Gilbert & D.W.Hughes
"Magnetic diffusion and dynamo action in shallow-water MHD" **Thur 18th 14.00-16.00: Sixth session**

The equations of shallow-water magnetohydrodynamics (SWMHD) are often used to model waves and instabilities in thin stratified layers in stellar and planetary atmospheres, in the perfectly-conducting limit. However, the addition of some sort of magnetic diffusion is crucial for modelling instabilities and turbulence, in part to provide an accurate balance with advection in the induction equation. For the straightforward choice of Laplacian magnetic diffusion, fundamental mathematical and physical inconsistencies arise in the equations of SWMHD, and unphysical dynamo action can arise. We derive a physically-consistent magnetic diffusion term by performing an asymptotic analysis of the three-dimensional equations of MHD in the thin-layer limit, giving the resulting diffusion term explicitly in both planar and spherical coordinates. We show how this magnetic diffusion term, which allows for a horizontally varying diffusivity, is consistent with the standard SWMHD solenoidal constraint, leads to negative semi-definite Ohmic dissipation, and precludes dynamo action.

Zhao Guo (University of Cambridge), Gordon Ogilvie & Adrian Barker
"Tidally excited gravity waves in the cores of solar-type stars: resonances and critical-layer formation"
Thur 18th 09.30-11.00: Fourth session

We simulate the propagation and dissipation of tidally induced nonlinear gravity waves in the cores of solar-type stars. We perform hydrodynamical simulations of a previously developed Boussinesq model using a spectral-element code to study the stellar core as a wave cavity that is periodically forced at the outer boundary with a given azimuthal wavenumber and an adjustable frequency. For low-amplitude forcing, the system exhibits resonances with standing g-modes at particular frequencies, corresponding to a situation in which the tidal torque is highly frequency-dependent. For high-amplitude forcing, the excited waves break promptly near the centre and spin up the core so that subsequent waves are absorbed in an expanding critical layer, as found in previous work, leading to a tidal torque with a smooth frequency- dependence. For intermediate-amplitude forcing, we find that linear damping of the waves gradually spins up the core such that the resonance condition can be altered drastically. The system can evolve towards or away from g-mode resonances, depending on the difference between the forcing frequency and the closest eigenfrequency. Eventually, a critical layer forms and absorbs the incoming waves, leading to a situation similar to the high-amplitude case in which the waves break promptly. We study the dependence of this process on the forcing amplitude and frequency, as well as on the diffusion coefficients. We emphasize that the small Prandtl number in the centre of solar-like stars facilitates the development of a differentially rotating core owing to the nonlinear feedback of waves. Our simulations and analysis reveal that this important mechanism may drastically change the phase of gravity waves and thus the classical picture of resonance locking in solar-type stars needs to be revised.

Parag Gupta (Glasgow University)
"Effects of Radial Variation of Viscosity and Entropy" **Poster**

Diffusivity on Convection and Dynamo Action in Rotating Spherical Shells In this study, we investigate the impact of radial variations in viscosity and entropy diffusivity on the dynamics of convection and dynamo action in density-stratified rotating spherical fluid shells. We use a 3D simulation code to obtain solutions of a physically consistent Anelastic model with a minimum number of parameters.

Our findings indicate that the Prandtl number has a significant influence on convective velocity and differential rotation profile, with higher Prandtl numbers leading to conical differential rotation. We also demonstrate that introducing radial variations in viscosity and entropy diffusivity can make the differential rotation more conical and alter the location of convection columns. Additionally, we explore how changes in the Rayleigh number affect the velocity profile in each of the three sequences, further affecting the differential rotation profile. Our results provide a better understanding of the dynamics of convective and dynamo action in spherical fluid shells. While in this study, we assume the same viscosity and entropy diffusivity ratio throughout the shell, our future work aims to investigate the effect of radial distribution of these parameters by assuming a large Prandtl number on the inner boundary and a small Prandtl number on the outer boundary of the spherical shell.

Anna Guseva (University of Leeds) & Steven Tobias
"Transition to chaos in magnetized Taylor–Couette flow" **Wed 17th 11.00-12.30: First session**

Taylor–Couette flow (TCF) is often used as a simplified model for complex rotating flows in the interior of stars and accretion discs. The flow dynamics in these objects is influenced by magnetic fields. For example, quasi-Keplerian flows in Taylor–Couette geometry become unstable to a travelling or standing wave in an external magnetic field if the fluid is conducting; there is an instability even when the flow is hydrodynamically stable. This magnetorotational instability leads to the development of chaotic states and, eventually, turbulence, when the cylinder rotation is sufficiently fast. The transition to turbulence in this flow can be complex, with the coexistence of parameter regions with spatio-temporal chaos and regions with quasi-periodic behaviour, involving one or two additional modulating frequencies. Although the unstable modes of a periodic flow can be identified with Floquet analysis, here we adopt a more flexible equation-free data-driven approach. We analyse the data from the transition to chaos in the magnetized TCF and identify the flow structures related to the modulating frequencies with Dynamic Mode decomposition; this method is based on approximating nonlinear dynamics with a linear infinite-dimensional Koopman operator. With the use of these structures, one can construct a nonlinear reduced model for the transition.

Scott Hopper (Newcastle University), Paul Bushby, Toby Wood
"Stratified Resistive Tearing Modes **Poster**

The resistive tearing mode, first mathematically modelled by Furth et al (1963), frequently arises in fluids with complex magnetic field configurations and finite conductivity. This instability has so far only been fully analytically solved in the case of an inviscid, incompressible, unstratified fluid. Other cases have been solved in the limit of a small growth rate, but the solutions do not give the fastest growing mode. It is believed that tearing instabilities may be present within the tachocline, competing with magnetic buoyancy to influence the latitudes at which sunspots arise. This therefore motivated us to generalise the full analytical solution under the Boussinesq approximation to account for stratification – a key feature of the tachocline's composition.

Susanne Horn (Coventry University) & Jonathan Aurnou
"The Elbert Range of Turbulent Rotating Magnetoconvection" **Poster**

Rotating magnetoconvection is characterised by rich multimodal flow behaviours. Depending on the control parameters, a mix of boundary-attached, oscillatory, and geostrophic, magnetostrophic, and magnetic stationary modes constitutes the dynamic of the system (Horn & Aurnou, Proc. R. Soc. A, 478, 2022). Specifically, when thermal convection is subject to both a strong magnetic field and rapid rotation, two very distinct stationary modes can co-exist: a small-scale geostrophic and a large-scale magnetostrophic modes. This so-called Elbert range is geophysically the most relevant parameter regime (named after Donna DeEtte Elbert, who first discovered this unique property of rotating magnetoconvection (Chandrasekhar, Clarendon, 1961).

Here, we will present results from direct numerical simulations (DNS) of turbulent thermal rotating magnetoconvection inspired by the original liquid mercury experiments by Nakagawa (Proc. R. Soc. A, 249, 1959). The DNS are conducted in a fluid with a Prandtl number of $Pr = 0.025$ contained in a wide cylinder with aspect ratio $\Gamma = 8$ and the rotation is kept fixed at an Ekman number of $Ek = 1.2 \times 10^{-4}$. We will discuss how the flow morphology, characteristic length scales and frequencies change with the magnetic field strength by varying the Chandrasekhar number in the range of $9.5 \times 10^1 \leq Ch \leq 5.0 \times 10^5$, corresponding to Elsasser numbers of $0.01 \leq \Lambda \leq 60$. We will focus on the Elbert range and explore if and how magnetostophic convection can create large length scales and thus provide favourable conditions for the dynamo generation in planetary cores.

Emma Hunter (University of Glasgow)
"Magnetoconvection simulations in the Busse annulus model" **Wed 17th 15.30-17.10: Third session**

Convection occurs naturally in the electrically conducting fluid regions of many astrophysical and geophysical bodies. It is believed that these convective fluid regions generate and maintain magnetic fields via dynamo action. Therefore an understanding of convection is necessary in order to gain a deeper understanding of how these magnetic fields are generated. In this talk we present non-linear magnetoconvection simulations in the Busse annulus, a 2D simplified model of spherical geometry. We compare our results with those of the non-magnetic case, in order to understand the effect of an imposed magnetic field on the zonal flows and multiple jets found in previous work. We also examine the magnitude of the forces involved in the system by considering the lengthscale dependent force balance spectra, allowing us to identify different regimes.

Andrei Igoshev (University of Leeds) & Rainer Hollerbach
"Neutron stars with off-centre dipole magnetic fields" **Wed 17th 15.30-17.10: Third session**

Off-centred dipole configurations have been suggested to explain different phenomena in neutron stars, such as natal kicks and irregularities in radio polarisation of pulsars. Here for the first time we model magneto-thermal evolution of neutron stars with crust-confined magnetic fields and off-centred dipole moments. We find that the dipole shift decays by10The off-centred dipole has a significant effect on surface thermal maps, dividing them into two parts with unequal sizes. In order to test if the amount of shift can be measured in timing and spectroscopic X-ray observations, we produce synthetic lightcurves and spectra for different orientations of the neutron star. We conclude that spectral X-ray observations could be used to examine the dipole shift as an addition to the radio polarisation measurements.

Rekha Jain (University of Sheffield) & Bradley Hindman
"Gravito-inertial waves in the solar interior" **Thur 18th 09.30-11.00: Fourth session**

We explore how low-amplitude gravito-inertial waves propagate within the gravitationally stratified atmosphere of the Sun's convective zone. We derive and solve a local dispersion relation for atmospheric waves in a fully compressible stratified and uniformly rotating fluid. After brief discussion on the propagation of gravito-inertial waves in an isothermal and isentropic atmospheres we focus on Thermal Rossby waves in an unstably stratified atmosphere that models the Sun's convective zone. We show the conditions for the radial trapping of the Thermal Rossby waves and suggest that stable Thermal Rossby waves could exist in the lower parts of the Sun's convection zone, despite being unstably stratified. For long wavelengths, the Sun's rotation rate is sufficiently rapid to stabilize convective motions and the resulting overstable convective modes are identical to Thermal Rossby waves.

Daniel Johnson (University of St Andrews) & Alan Hood
"The Importance of Coronal Magnetic Null Points on the Thermodynamics of Coronal Heating " **Wed 17th 15.30-17.10: Third session**

Magnetic null points are regions of a magnetic field where the strength of the field vanishes. Magnetic null points play an important role in a variety of processes that (to some extent) may be linked with coronal heating, including their ability to influence the propagation of waves, their tendency to host currents and their role in magnetic reconnection. Hence, thermal energy may be introduced into a system at (or near) a null point via some process (e.g. Ohmic dissipation or magnetic reconnection). Where the magnetic field strength is finite, thermal conduction is aligned with the magnetic field, but at a magnetic null point thermal conduction becomes isotropic. Therefore, in addition to being important for the introduction of thermal energy into a system, null points also introduce interesting constraints on the thermodynamics of coronal heating via the nature in which thermal energy propagates at a null point. A full understanding of the importance of magnetic null points on the thermodynamics of coronal heating is yet to be achieved. In this presentation we discuss the influence that a null point has on the flow of thermal energy in a system and the consequences this may have on coronal heating.

Tom Joshi-Cale (University of Exeter), Matthew Browning, Laura Currie, Evan Anders, Benjamin Brown & Whitney Powers;
"Investigating the Effects of Internal Heating and Cooling on Convective Heat Transport" **Poster**

The Mixing-Length Theory of turbulent Rayleigh-Bénard convection – often used to model stellar interiors - predicts a Nusselt-Rayleigh scaling relationship of Ra$^{1/2}$ – sometimes known as the 'ultimate' scaling – and this occurs if heat transport becomes independent of molecular diffusivities. However, in the majority of studies to date, the 'classical' scaling of Ra$^{1/3}$ has been observed, due to thermal boundary layers in the fluid throttling the transport. By imposing a net-zero heating and cooling function across the fluid prior work has recovered the 'ultimate' scaling. Here, we present direct numerical simulations, in 2- and 3-dimensions, of both classical boundary-driven convection and net-zero internally heated convection. We examine the circumstances under which the classical and ultimate scalings are recovered. We also vary the width of the heating and cooling functions to assess how the scaling relationship is affected, with the goal of extrapolating to solar-like conditions.

Alexander Kimbley (University of Leeds), Stephen Griffiths & David Hughes
"Nonlinear evolution of axisymmetric instabilities in stellar and planetary atmospheres" **Thur 18th 11.30-12.50: Fifth session**

The large-scale circulations of the atmospheres and interiors of many planets and stars are dominated by parallel flows. The stability of such flows, and how it depends upon background rotation, shear, stratification and magnetic field, is important for constraining the possible flow configurations and for understanding the development of turbulence. We first consider linear axisymmetric inertial instabilities in a uniformly stratified fluid on an f-plane, for an unbounded shear layer in the presence of a vertical magnetic field. For linear normal modes with vertical wavenumber k, the dynamics are governed by a second order ODE that yields an explicit expression for the growth rate. In the absence of magnetic field there is only a single mode, which, provided the absolute vorticity is negative, can be identified as an inertial instability for some interval of k and is well understood in the context of the terrestrial atmosphere. Vertical magnetic field allows purely magnetic instabilities to occur when the absolute vorticity is positive (i.e., in the hydrodynamically stable regime) provided there is anti-cyclonic shear; we discuss to what extent these instabilities relate to the MRI. We then consider the nonlinear evolution of magnetically-modified inertial instabilities for a hyperbolic tangent flow, focussing both on the saturation of the instabilities via changes to the mean flow and on the role played by the magnetic field.

Velizar Kirkow (University of Exeter), Joanne Mason & Andrew Gilbert
"Modelling instabilities in Astrophysical Fluid Dynamics" **Poster**

We investigate the stability of a 2-D sinusoidal shear flow in the MHD (magnetohydrodynamic) regime using both linear and weakly nonlinear stability theory. We are supposing that the fluid is stably stratified and that there is an initially horizontal uniform magnetic field acting on it. We consider the fluid to be incompressible and we use the Boussinesq approximation to incorporate the effects of buoyancy. Building on previous work done in the hydrodynamic framework, we show what effect the magnetic field has on the stability of the stratified fluid where we have assumed periodic boundary conditions. The results investigating the stability of the system we present are both of a numerical and analytical nature and we show how they corroborate each other. We find that the fluid is stabilised under the effects of a weak magnetic field and weak heat coupling as well as preliminary results how at high Reynolds numbers, increasing the magnetic field strength can destabilise the fluid at different levels of stable stratification.

S. Lalloz (Coventry University), A. Pothérat, L. Davoust & F. Debray
"Characterisation of confined Alfvén waves at low magnetic Reynolds number " **Wed 17th 15.30-17.10: Third session**

MHD Turbulent flows at low magnetic Reynolds number (Rm) have been extensively studied over the last 60 years and are understood to be governed by a pseudodiffusive process of momentum caused by Lorentz forces. Sommeria and Moreau (1982) provide quantitative interpretation of this process by introducing a bidimensionalization time characterizing this pseudo-diffusive process. However, it has never been clear whether the dominance of the diffusive effects of the Lorentz force necessarily implies that propagative effects in low-MHD are absent. In other words, can Alfvén wave still exist and if, so what is their dynamics. So far, this question has received limited attention for the simple reason that, at low Rm, it is technically difficult to observe the propagation of Alfvén waves in laboratory conditions. Thus, since their theorization in 1942, only few studies paid attention to their characterization at low Rm (Lundquist (1949), Lehnert (1954), Jameson (1964), Alboussiere (2011)). Here, we overcome these technical limitations by forcing Alfvén waves electrically in a liquid metal at much higher magnetic fields than available for the early studies. To this end, a revisited version of the Flowcube apparatus, which was initially designed to study MHD turbulence in detail (Pothérat & Klein (2014)) is used to investigate Alfvén waves. The device is a cubic container placed in a vertical, static and homogeneous magnetic field of up to 10T. Wave forcing is performed by injecting an AC current through an array of electrodes located at the vessel bottom wall, so that the forcing intensity, the wave frequency and the transverse forcing scale to the magnetic field can be electrically controlled. Waves are tracked by means of two arrays of potential probes positioned in mirror symmetry to each other and placed at opposite walls of the cube. This measurement technique makes it possible to characterise wave propagation (attenuation, velocity, patterns) along the directions parallel and orthogonal to the magnetic field. Experimental results are interpreted in the light of an analytical model of forced Alfvén waves in a bounded geometry and at low Rm. Through this study, we confirm that Alfvén waves indeed propagate at low Rm, in line with historical experimental studies. Interestingly, we found non-homogeneous propagation of Alfvén waves, especially near the point where the forcing current is injected into the fluid point. It appears that Alfvén wave propagation is strongly influenced by the geometry of the system, an important effect that is not captured by the classical theory of homogeneous Alfvén waves.

A. Teimurazov, **Matthew McCormack** (University of Edinburgh), M. Linkmann & O. Shishkina
"Connecting buoyancy dominated and magnetically dominated regimes in magnetoconvection" **Thur**

18th 11.30-12.50: Fifth session

A long-standing question in thermal convection under the action of a magnetic field is how the dimensionless convective heat transport (Nu-1, where Nu is the Nusselt number) scales with the dimensionless thermal driving (Rayleigh number Ra) and the strength of the magnetic field (Hartmann number Ha), in different regimes. In magnetoconvection, where an electromagnetically conductive fluid is influenced by a vertical magnetic field, one may expect a scaling Nu$-1 \sim$ Ra$^{\gamma}$ in the buoyancy dominated (BD) regime and Nu$-1 \sim (\mathrm{Ra}/\mathrm{Ra_c})^{\xi}$ in the magnetically dominated (MD) regime, where $\mathrm{Ra_c} = \mathrm{Ra_c}(\mathrm{Ha})$ is the critical Ra for the onset of magnetoconvection. In this talk, we extend the analytic scaling theory of Ecke & Shishkina (Annu. Rev. Fluid Mech. 55, 603–638 (2023)), which was originally developed for rotating Rayleigh–Benard convection (RBC), to the case of RBC under the action of a vertical magnetic field. The theory connects the BD and MD regimes, allowing for prediction of the scaling behaviour in strongly MD convection from only the measurement of the scaling exponent in the BD regime and vice versa. Further, we construct a scaling law that predicts the transition between these two regimes. The theory is supported by both direct numerical simulations and experiments.

Hemanthi Miriyala (Northumbria University), Richard Morton, Elena Khomenko, Patrick Antolin
"Double Mode Conversion In Sunspots" **Fri 19th 11.30-13.00: Eighth session**

Sunspots are intense regions of magnetic flux that are rooted deep below the photosphere. It is well established that they host Magnetohydrodynamic waves, with numerous observations showing a connection to the internal acoustic (or p) modes of the Sun. The p-modes are fast waves below the equipartition layer, and undergo a double mode conversion as they propagate upwards into the atmosphere of sunspots, which can generate Alfvénic modes in the upper atmosphere. We employ 2.5D numerical simulations to investigate the adiabatic wave propagation and examine the resulting power spectra of coronal Alfvénic waves. A realistic, non-monochromatic wave source is employed, with power spectra that closely resemble that of p-modes. We examine magnetoacoustic wave propagation from the photosphere to the lower chromosphere by perturbing the atmosphere below the photospheric level, generating upward propagating magnetoacoustic waves. The wave modes generated higher in the atmosphere depend on the magnetic field inclinations, the ratio of Alfvén speed (v_A) and sound speed (c_s), and the location of the driver. We demonstrate the role of magnetic field inclination has on modifying the Alfvénic power spectra through the sensitivity of the cut-off frequency and degree of mode conversion to inclination.

Krzysztof Mizerski (Institute of Geophysics, Polish Academy of Sciences)
"Non-equilibrium effects in mean-field dynamos" **Wed 17th 13.30-15.00: Second session**

When turbulence is not in equilibrium, i.e. statistically non-stationary, the standard alpha-effect is modified by new contributions, which remain non-zero even when the resistivity of the fluid tends to zero. I will review the recent theoretical results on this topic and explain the physical mechanism of the non-equilibrium dynamo process.

Sam Myers (University of Leeds)
"Linear stability of a parallel 2D MHD flow with an aligned magnetic field" **Poster**

The hyperbolic-tangent velocity profile is well known to be hydrodynamically unstable. We will show that imposing different aligned magnetic fields can either stabilise or further destabilise this flow, sometimes introducing a new mode at larger wavenumbers with a larger growth rate.

Junho Park (Coventry University)

“Prandtl number dependence on shear flow instabilities” **Thur 18th 11.30-12.50: Fifth session**

Thermal diffusion and stratification have crucial impacts on many naturally occurring and engineering systems where fluid flow is coupled with heat transfer. The thermal diffusion in fluid flows is characterised by the Prandtl number Pr=nu/kappa, which is a ratio between fluid kinematic viscosity nu and thermal diffusivity kappa. Depending on fluids, the Prandtl number varies: for instance, P$\gg 1$ for oils, Pr= $O(1)$ for gases, Pr= $O(0.01)$ for liquid metals, and Pr= $O(10^{-6})$ in the solar and stellar radiation zones. For shear flow in stably stratified fluids, the effect of the stratification inhibiting the vertical motion of fluids can be suppressed at a low Prandtl number where the thermal diffusivity is high. This was studied in the context of shear instability where both stratification and shear are along the vertical direction (Lignières et al. 1999 A&A). Motivated by relevance to some geophysical and astrophysical flows, we will discuss in the presentation how high thermal diffusivity alters the nature of flow instabilities for other types of shear flow; for instance, (i) inertial and inflectional instabilities of horizontal shear flows in stratified-rotating fluids, or (ii) centrifugal and strato-rotational instabilities of stratified Taylor-Couette flow.

Oliver Rice (Durham University) & Anthony Yeates
“Eruptivity Criteria of Magnetic Flux Ropes in the Solar Corona” **Fri 19th 11.30-13.00: Eighth session**

We investigate which scalar quantity or quantities can best predict the loss of equilibrium and subsequent eruption of magnetic flux ropes in the solar corona. In our models the flux rope is produced self-consistently by flux cancellation combined with gradual footpoint shearing of a coronal arcade that is open at the outer boundary. This models the magnetic field in decaying active regions on the Sun. We use both full MHD in cartesian coordinates and the magnetofrictional approach in cartesian and polar coordinates. The flux ropes are translationally-invariant, allowing for very fast computational times and thus a comprehensive parameter study, comprising hundreds of simulations and thousands of eruptions. We observe that the flux rope behaviour is similar using either magnetofriction or MHD, and that there are several scalar criteria that could theoretically be used as a proxy for eruptivity. We find the most consistent predictor of eruptions in either model is the squared rope current normalised by the relative helicity, although a variation on the previously proposed ‘eruptivity index’ is also found to perform well in the MHD simulations.

Calum S. Skene (University of Leeds), Jeffrey S. Oishi, Peter Gilman & Steven M. Tobias
“Magnetohydrodynamic instabilities in the solar tachocline using a numerical anelastic spherical shell model with differential rotation” **Fri 19th 09.30-11.00: Seventh session**

The solar tachocline is a region in the Sun that transitions between the radiative zone, which rotates as a solid body, and the differentially rotating convection zone. Even though it is a thin region with a radial extent of around 4% of the Sun’s total radius, it is believed to be important in the solar dynamo problem. Recently, Gilman (ApJ 2018) found instabilities in the tachocline analytically using thin-shell anelastic equations and by considering instabilities with small latitudinal scales. In this study, both rotational and magnetic buoyancy instabilities were found, giving insights into the link between instabilities in the tachocline and solar phenomena such as sunspot formation and the possibility of a thicker tachocline at high latitudes.

Here we investigate potential tachocline instabilities numerically using the full anelastic equations in a spherical shell. For this purpose the open source PDE solver Dedalus is used to discretise the anelastic equations in a spectral basis, and subsequently solve for the eigenvalues. We discuss our findings for both stable hydrodynamic modes, and also for MHD with a toroidal magnetic field. For small diffusion we compare our results with the local theory of Gilman.

Ben Snow (University of Exeter), Andrew Hillier & Inigo Arregui
"Mixing induced cooling in the solar atmosphere" **Fri 19th 11.30-13.00: Eighth session**

In many astrophysical systems mixing between cool and hot temperature gas/plasma through Kelvin-Helmholtz-instability-driven turbulence leads to the formation of an intermediate temperature phase with increased radiative losses that drive efficient cooling. The solar atmosphere is a potential site for this process to occur with interaction between either prominence or spicule material and the solar corona allowing the development of transition region material with enhanced radiative losses. In this talk, I will derive a set of equations to model the evolution of such a mixing layer and make predictions for the mixing-driven cooling rate and the rate at which mixing can lead to the condensation of coronal material. These theoretical predictions are benchmarked against 2.5D MHD simulations. Applying the theoretical scalings to prominence threads or fading spicules we found that as a mixing layer grows on their boundaries this would lead to the creation of transition region material with a cooling time of 100s, explaining the warm emission observed as prominence threads or spicules fade in cool spectral lines without the requirement for any heating. Overall, this mechanism of thermal energy loss through radiative losses induced by mixing highlights the importance for considering dynamical interaction between material at different temperatures when trying to understand the thermodynamic evolution of the cool material in the solar corona.

Ramada Sukarmadji (Northumbria University), Patrick Antolin, James McLaughlin & Paolo Pagano
"Numerical experiments on the role of Alfvén waves in triggering nanojets" **Wed 17th 11.00-12.30: First session**

Nanojets are nanoflare-sized bursts transverse to the guidefield produced by small-angle component reconnection events. They have been observed in many coronal loop-like structures including a prominence-coronal rain hybrid structure (Antolin et al. 2021), a coronal loop powered by a blowout jet, and in coronal loops with coronal rain (Sukarmadji et al. 2022). However, we have a limited number of nanojet observations due to their small-scales of < 1000 km in length and short timescales of < 30s. This presents a challenge to figure out how nanojets are generated, and we therefore need to utilise high-resolution numerical MHD simulations to further understand their driving mechanisms. We present numerical simulation results of nanojets using the PLUTO code. Our initial condition is a simple initial model towards a braiding scenario based on Antolin et al. (2021); where we simulated two straight and adjacent flux tubes that are driven to form a small misalignment. We then introduce Alfvén waves into the tubes through footpoint driving. From the results, we show that Alfvén waves can serve as the trigger of reconnection events by locally increasing the shear angle from the braiding. We also find that the reconnection produces nanojet-like structures with similar velocities and energy releases as found in the observations. Alfvén waves may therefore play an important role in facilitating small-angle reconnection, nanojets and heating.

Jordan Talbot (Northumbria University)
"Independence of Oscillatory Reconnection Periodicity from Resistivity" **Fri 19th 11.30-13.00: Eighth session**

With the ubiquity of both MHD waves and magnetic null points within the solar atmosphere, there is an inevitability that they will interact. It has been shown, primarily through numerical simulations, that one way in which they can come together is through wave driven oscillatory reconnection. There has been a significant increase in the international interest in oscillatory reconnection, its properties and how it can act as a plasma heating mechanism, particularly for the origin of Quasi-Periodic Pulsations in solar flares, and how different parameters can affect the period of the oscillations within the system. In this study, we simulate, using the Lare2d numerical code, an oscillatory reconnection system with levels of resistivity varying across 7 orders of magnitude, as well as an ideal MHD scenario, to find the relationship between resistivity and period. Using a combination of wavelet analysis, Fourier spectra and statistical tests, we find that there is no significant change in period due to a change in the value of resistivity, which suggests an independence in oscillatory reconnection periodicity from resistivity, contradicting the analytical results of Craig & McClymont (1991). We will also discuss the numerical techniques used to prevent boundary reflections interfering with the simulation and present a study into the effects of Kuropatenko numerical artificial shock viscosities, utilised in the Lare2d code, when simulating oscillatory reconnection, focusing on how changes in the level of these viscosities affects the period of the system and the overall evolution of this system.

Rob Teed (University of Glasgow) & Emmanuel Dormy
"Solenoidal force balances in geodynamo models" **Wed 17th 13.30-15.00: Second session**

Numerical simulations of the geodynamo (and other planetary dynamos) have made significant progress in recent years. As computing power has advanced, some new models claim to be ever more appropriate for understanding Earth's core dynamics. One measure of the success of such models is the ability to replicate the expected balance between forces operating within Earth's core; Coriolis and Lorentz forces are predicted to be most important. The picture is complicated by the existence of the pressure gradient force which renders the gradient parts of all other forces dynamically unimportant.

In this work we investigate force balances through the alternative approach of eliminating gradient parts of each force to form 'solenoidal force balances'. We perform a lengthscale dependent analysis for several geodynamo simulations and find that removal of gradient parts offers an alternative picture of the force balance compared to looking at traditional forces alone. If time allows, we shall also examine the use of solenoidal forces to identify dynamo regimes across parameter space.

Yue-Kin Tsang (Newcastle University)
"Oscillatory double-diffusive convection in a rotating spherical shell: a preliminary survey " **Poster**

We consider a Boussinesq fluid in a rotating spherical shell whose density depends on both the temperature and composition (concentration of heavy elements in our case). We focus on the regime of oscillatory double-diffusive convection (ODDC) where the equilibrium temperature gradient across the shell is destabilising and the equilibrium composition gradient is stabilising (i.e. warm and heavy at the bottom). In the absence of composition, there is a critical thermal Rayleigh number Ra_0 below which motion is not sustained. An intriguing feature of ODDC is that motion becomes possible below Ra_0 despite composition is supposed to have a stabilising effect. Here we survey the types of flow pattern developed in ODDC for thermal Rayleigh number below and slightly above Ra_0. We consider both cases of positive and negative squared buoyancy frequency.

Riccardo Vanon (University of Leeds)
"Internal Gravity Waves in intermediate mass stars: age dependence **Wed 17th 11.00-12.30: First session**

We carried out 3D full star simulations of $7M_\odot$ stars at three different ages: ZAMS, midMS and TAMS. We compare various aspects of these simulations to analyse differences in internal gravity wave (IGW) generation and propagation, chemical mixing and angular momentum transport as a function of stellar age.

Matt Vine (University of Leeds)
"Influence of a Magnetic Field on Stellar Internal Waves" **Thur 18th 11.30-12.50: Fifth session**

Internal waves are known to propagate in the stably-stratified radiative zones of many stars. Perhaps the most widespread reason for studying these waves is the chemical mixing they induce, particularly when they break. Mixing of Hydrogen and Helium in stellar interiors has implications for stellar evolution. We focus on planar internal waves and adopt the Boussinesq approximation. Historically, much of the literature regarding internal waves in this mathematical setting has taken place in the absence of a magnetic field. In keeping with the magnetic interior of many stars, we incorporate MHD in our model and consider the impact of doing so in comparison with hydrodynamic literature. Some of the questions we address in this talk include: (1) How does the field affect the phase and group velocity of these waves? (2) How does a field affect the stability of these waves?

Daining Xiao (Durham University), Chris Prior & Anthony Yeates
"Spherical Winding and Helicity" **Wed 17th 11.00-12.30: First session**

Magnetic helicity has been widely used as a diagnostic tool in the analysis of solar magnetic activities and global modelling of the solar atmosphere. However, for open magnetic fields, i.e., those with non-zero normal boundary components, the interpretation of the exact values of helicity is challenging due to their susceptibility to gauge transformations. Recently, we extended the intrinsic, geometrical measure of helicity from Cartesian to spherical domains with greater astrophysical significance, showing that open-field helicity is equivalent to the average flux-weighted pairwise winding numbers of field lines. We also quantitatively investigated the influence of spherical geometry on helicity density calculations using magnetogram data from HMI/SHARP (Spaceweather HMI Active Region Patch), and we found that the Cartesian approximations remain mostly valid even for active regions with large spatial extents or strong field strengths.

List of Attendees

Wayne Arter UKAEA
Adrian Barker University of Leeds
Gert Botha Northumbria University
Paul Bushby Newcastle University
Laura Currie Durham University
Nils de Vries University of Leeds
Javiera Katalina Diaz Berrios University of Leeds
Craig Duguid Newcastle University
Robert Dymott University of Leeds
Jian Fang Daresbury Laboratory, STFC
Lucas Gosling University of Leeds
Luke Gostelow University of Leeds
Stephen Griffiths University of Leeds
Parag Gupta University of Glasgow
Anna Guseva University of Leeds
Zhao Guo University of Cambridge
Scott Hopper Newcastle University
Susanne Horn Coventry University
David Hughes University of Leeds
Emma Hunter University of Glasgow
Andrei Igoshev University of Leeds
Rekha Jain University of Sheffield
Daniel Johnson University of St Andrews
Chris Jones University of Leeds
Tom Joshi-Cale University of Exeter
Evy Kersalé University of Leeds
Jo Kershaw University of Leeds
Alexander Kimbley University of Leeds
Velizar Kirkow University of Exeter
Samy Lalloz Coventry University
Phil Livermore University of Leeds
Joanne Mason University of Exeter
Matthew McCormack University of Edinburgh
George McGilvray University of Leeds
Hemanthi Miriyala Northumbria University
Krzysztof Mizerski Polish Academy of Sciences
Jonathan Mound University of Leeds
Sam Myers University of Leeds
Rhiannon Nicholls University of Leeds
Junho Park Coventry University
Alban Pothérat Coventry University
Oliver Rice Durham University
Graeme Sarson Newcastle University
Ayesha Sarwar University of Glasgow
Curtis Saxton University of Warwick
Calum Skene University of Leeds
Radostin Simitev University of Glasgow
Ben Snow University of Exeter
Sage Stanish University of Glasgow
Ramada Sukarmadji Northumbria University
Robert Teed University of Glasgow

Steven Tobias University of Leeds
Jordan Talbot Northumbria University
Yue-Kin Tsang Newcastle University
Riccardo Vanon University of Leeds
Matthew Vine University of Leeds
Fryderyk Wilczynski University of Leeds
Toby Wood Newcastle University
Daining Xiao Durham University