UKMHD

University of Exeter

June 26th and 27th

Programme and Book of Abstracts

University of Exeter

Day 1 - start 13:00

Registration 13:00 – 13:30

Opening statement 13:30

Session 1: 13:35 – 15:45 (Solar Atmosphere) Chair: Andrew Hillier

13:35-14:05 Tony Arber (University of Warwick) **Invited Talk** (presented by Ben Snow)
The Solar Atmospheric Modelling Suite: First Steps and Future Plans

14:05 - 14:22 Samuel Hor (Northumbria University)
Constraining secondary heating sources in flares through numerical modelling

14:22 - 14:39 Ryan Smith (Northumbria University)
Fast magnetoacoustic wave behaviour within magnetically-inhomogeneous, gravitationally-stratified media

14:39 - 14:56 Tahlina Borradaile (Aberystwyth University)
Effect of field line expansion on the energy flux of Alfvén Waves in the solar atmosphere

14:56 - 15:13 Samy Lalloz (Coventry University) (presented by Alban Pothérat)
Distorted Alfvén waves in liquid metal experiments to address the solar corona heating problem

15:13 - 15:30 Thomas Neukirch (University of St Andrews)
Analytical Three-dimensional Magnetohydrostatic Equilibria in Spherical Geometry

Coffee in poster room 15:30 - 16:00

Session 2: 16:00 – 17:30 (Turbulence and Dynamos) Chair: Joanne Mason

16:00 - 16:17 Erin Goldstraw (The University of Edinburgh)
Energy Fluxes in Reduced Magnetohydrodynamic Turbulence

16:17 - 16:34 Asif Nawaz (The University of Edinburgh)
Physics-based models for large-eddy simulations of (un)steady magnetohydrodynamic turbulence

16:34 - 16:53 Emma Hunter (University of Glasgow)
Lengthscale dependence of triple force balances in dynamo simulations

16:53 - 17:10 Ayesha Sarwar (University of Glasgow)
Force balances characteristic of different dynamo regimes

17:10 - 17:27 Craig Duguid (Durham University)
Dynamo action in the solar tachocline

Conference Dinner at 18:30 by Reed Hall (outside weather permitting)

Day 2 – start 9:00

Session 3: 9:00 – 10:20 (Convection) **Chair: Rob Teed**

9:00 - 9:30 Susanne Horn (Coventry University) **Invited talk**
Low-Rm Rotating Magnetoconvection: Linear Theory, Simulations, Experiments and Extrapolation to Planetary Core Settings

9:30 - 9:47 Jo Kershaw (University of Leeds)
Dynamics of rotating convection in Earth's outer core

9:47 - 10:04 Matthew Lawrence (University of Leeds)
Magnetoconvection with depth-dependent magnetic diffusivity

10:04 - 10:21 Sonny Burrell (University of Leeds)
Fluid instabilities in differentially rotating radiation zones with compositional gradients

Coffee break and poster session 10:20 - 11:20

Session 4: 11:20 – 13:00 (Instabilities) **Chair: Gordon Ogilvie**

11:20 - 11:50 Luke Gostelow (University of Glasgow) **Invited talk**
Shear instability and semicircle theorems in QGSW MHD

11:50 – 12:07 Velizar Kirkow (University of Exeter)
Shear-driven instabilities in stratified MHD with application to the solar tachocline

12:07 - 12:24 Scott Hopper (Newcastle University)
Instabilities in the Solar Tachocline

12:24 - 12:41 Matt Vine (University of Leeds)
Instabilities of Alfvén-Gravity Waves in Stably-Stratified MHD

12:41 – 12:58 Manohar Teja Kalluri (University of Exeter)
Role of reconnection in Rayleigh Taylor instability

Lunch 13:00 - 14:00

Session 4 Continued: 14:00 – 14:34 (Instabilities) **Chair: Andrew Hillier**

14:00 - 14:17 Wayne Arter
Spiking Behaviour in MHD

14:17 - 14:34 Muhammad Ishaq (Coventry University)
Weakly Nonlinear Analysis of Helical Magnetorotational Instability in Taylor–Couette Flow

Session 5: 14:34 – 15:42 (Astrophysical Disks)

14:34 - 14:51 Nicolas Brughmans (KU Leuven)
A visual approach to MHD accretion disk instabilities

14:51 - 15:08 Mattias Brynjell-Rahkola (University of Cambridge)
Self-sustaining dynamo states in astrophysical discs. Part 1: Solutions on the edge of chaos

15:08 - 15:25 Gordon Ogilvie (University of Cambridge)
Self-sustaining dynamo states in astrophysical discs, Part 2: Shearing waves and their electromotive forces

15:25 - 15:42 Chris Pringle (Coventry University)
Numerical diffusivity in MHD simulations of global accretion disc dynamos

Closing remarks 15:45 - 16:00

Speaker: Tony Arber (given by Ben Snow)

Institute: University of Warwick

Type of presentation: Invited Talk

Session: 1 (Solar atmosphere)

Title: The Solar Atmospheric Modelling Suite: First Steps and Future Plans

Abstract: STFC recently funded a 5-year project to develop the next generation of UK solar simulation software. The Solar Atmospheric Modelling Suite (SAMS) will be developed by researchers at Exeter, Glasgow, Sheffield, Cambridge and Warwick. It aims to develop packages which can be combined, or run in isolation, covering at a minimum non-local NLTE physics, chromospheric modelling, flux emergence, advanced diagnostics. This talk outlines the SAMS project so that the UK solar community is aware of SAMS and also able to comment and contribute in all stages of its development.

Speaker: Samuel Hor

Institute: Northumbria University

Type of presentation: Talk

Session: 1 (Solar atmosphere)

Title: Constraining secondary heating sources in flares through numerical modelling

Abstract: In the solar atmosphere the catastrophic cooling phenomena known as coronal rain plays an important role in the wider context of coronal heating. Understanding coronal rain can help us put spatial and temporal constraints on the properties of the heating mechanisms. Coronal rain is observed to occur commonly above active regions as "quiescent" coronal rain, as opposed to the flare-driven kind observed in almost every flare during the gradual phase. Our current hypothesis of how quiescent coronal rain is formed is the TNE-TI (Thermal non-Equilibrium Thermal Instability) mechanism, whereby coronal loops are unable to achieve thermal equilibrium because of strongly stratified and long-lived heating, leading to plasma catastrophically cooling, condensing, and falling as coronal rain. The standard flare model proposes that the bulk of the heating in flare loops is produced by non-thermal electrons accelerated by magnetic reconnection and precipitating down to the chromosphere. However, a notable problem with this model is that it is unable to explain the formation of flare-driven rain. In this work we use 1D RHD simulations with HYDRAD and apply the TNE-TI scenario to flares to explore the existence of a secondary heating source associated with the heating. We constrain the required heating location, duration, asymmetry and volumetric heating of such additional source needed to have coronal rain whose properties match those observed.

Speaker: Ryan Smith

Institute: Northumbria University

Type of presentation: Talk

Session: 1 (Solar atmosphere)

Title: Fast magnetoacoustic wave behaviour within magnetically-inhomogeneous, gravitationally-stratified media

Abstract: The nature of MHD waves within inhomogeneous media is fundamental to understanding and interpreting wave behaviour in the solar atmosphere. We investigate fast magnetoacoustic wave behaviour within magnetically-inhomogeneous, gravitationally-stratified media, by studying a magnetic environment containing a simple X-type magnetic null point. We find that the addition of gravitational stratification fundamentally changes the nature of the system, including breaking the symmetry, and that that there are two main governing effects: the stratified-density profile acts in combination with the vertical dependence of the magnetic field, creating a large gradient in the Alfvén speed and hence, a system replete with refraction. The system is investigated using both numerical simulation and a semi-analytical WKB solution (via Charpit's method and a fourth-order Runge-Kutta solver) and we find strong agreement between both. The results show a fundamental difference between the stratification-free and stratified cases, with significant unexpected behaviour, and we explain how these results fit into the pantheon of MagnetoAcousticGravity waves.

Speaker: Tahlina Borradaile

Institute: Aberystwyth University

Type of presentation: Talk

Session: 1 (Solar atmosphere)

Title: Effect of field line expansion on the energy flux of Alfvén Waves in the solar atmosphere

Abstract: Simulations and observations often show Alfvén waves in the solar atmosphere with sufficient power to heat the solar corona and accelerate the solar wind. It is long been accepted that low-frequency Alfvén waves are suppressed due to inhomogeneities and steep spatial gradients in the solar atmosphere, with high-frequency waves being rapidly damped in the solar atmosphere. The effect of the rate of field line expansion on Alfvén wave propagation across the frequency spectrum is largely unexplored. We present evidence that certain expansion factors may significantly enhance the energy flux of Alfvén waves that reach the solar corona. We investigate the temporal evolution of periodic and randomly driven Alfvén waves propagating along field lines of different expansion rates in a stratified solar atmosphere. Numerical techniques are employed in the simulation to solve the linearised equations of motion and induction, and the resulting energies and power spectra at the transition region are calculated for the different expansion rates.

Speaker: Samy Lalloz

Institute: Coventry University

Type of presentation: Talk

Session: 1 (Solar atmosphere)

Title: Distorted Alfvén waves in liquid metal experiments to address the solar corona heating problem

Abstract: Since their theorisation in 1942 (Alfvén, 1942), Alfvén waves are now known to be present in various geo-astrophysical environments (Mathioudakis et al., 2013; Gillet et al., 2010). These transversal hydromagnetic waves propagating along the magnetic field lines are, thus, expected to play an important role in the flow dynamics and energy transfers taking place in these environments. For instance, in the Sun, Alfvén waves are a good candidate for explaining the high temperature of the corona by carrying enough energy for corona heating (Jess et al., 2009). Yet, the underlying processes to explain how these waves can deposit their -mechanical and magnetic- energy into heat in the corona are still unclear. In fact, a simple approach shows that Alfvén waves propagate in this medium with almost no damping (Priest et al., 2001).

In this presentation, we tackle the question of the wave damping by showing the existence of two distinct Alfvén wave regimes: a first -homogeneous- Alfvén Waves regime (AW) where the wave is only damped by a diffusion process along the direction of the wave propagation, and a second -Distorted- Alfvén Waves regime (DAW), where the strong magnetic and velocity gradients in the directions perpendicular to the
wave propagation predominate in the wave damping. First, we clarify the range of existence of these two regimes in the space of parameters ($R\eta /k_\perp^2$, $Ha/(k_\perp \sqrt{Pm^{-1} - 1})$), where $R\eta$ is the resistive screen parameter, proportional to the wave frequency, Ha is the Hartmann number, proportional to the background magnetic field intensity, $k_\perp$ is the transverse wavenumber quantifying the intensity of the transverse gradients and Pm is the magnetic Prandtl number. Then, we investigate experimentally the properties of propagation in these two regimes using the Flowcube apparatus (Lalloz et al., 2025) at the LNCMI laboratory (France), the latter providing intense magnetic fields (up to 11T) in large diameter bore (400mm). We show that DAWs are Ha^2 times more damped than Alfvén waves in the AW regime. Thus, given that Ha is much larger than unity in the considered geo-astrophysical media, we suggest that the DAW regime is likely to play an important role in the still unclear sun corona heating.

Speaker: Thomas Neukirch

Institute: School of Mathematics and Statistics, University of St Andrews

Type of presentation: Talk

Session: 1 (Solar atmosphere)

Title: Analytical Three-dimensional Magnetohydrostatic Equilibria in Spherical Geometry

Abstract: Analytical solutions of the magnetohydrostatic equations in three dimensions are difficult to find. In this contribution the focus will be on a particular known method for finding such analytical solutions in spherical geometry. In this geometry the solutions can be expressed as sums over spherical harmonics with coefficient functions depending on the radial coordinate. Based on this method a number of possible solution families have been found in the past. We will present a new family of solutions in which the radial dependence is given by Airy functions. Possible applications could, for example, be the (global) solar corona or stellar magnetic fields.

Speaker: Erin Goldstraw

Institute: The University of Edinburgh

Type of presentation: Talk

Session: 2 (Turbulence and Dynamos)

Title: Energy Fluxes in Reduced Magnetohydrodynamic Turbulence

Abstract: Complex dynamics of a broad range of astrophysical, industrial plasmas and magnetofluids are well described by the magnetohydrodynamic(MHD) equations.
However, due to this inherent complexity, further assumptions are often required to gain results with available resources. A common feature of many plasmas is a strong magnetic field. One approximation that uses this assumption is called Reduced MHD(RMHD). This model is described as a nonlinear, low-frequency incompressible approximation to 3D compressible MHD. It correctly illustrates many known features of the strong mean-field limit of MHD, but clearly cannot capture the full picture. It is unclear exactly how the RMHD assumptions affect the transport of energy across scales, which dynamical processes are fully and correctly described and which are neglected. To identify the physical processes governing turbulent energy cascades that are retained in RMHD, we leverage an energy flux decomposition, that has recently been extended from hydrodynamics to MHD. This technique provides a clear framework to identify the processes present in 3D incompressible MHD turbulence by splitting the energy flux into subfluxes that originate from vortex stretching, strain self-amplification, current-sheet thinning or current-filament stretching, and to quantify their contribution to the energy cascade. The equations for the MHD fluxes are expanded using the RMHD approximation. Leading order terms help to identify the main processes in RMHD which are likely to be accurately modelled at this order, while higher order terms allow an insight into the importance of neglected terms. We discuss results for both high- and low-beta plasmas

Speaker: Asif Nawaz

Institute: School of Mathematics, The University of Edinburgh

Type of presentation: Talk

Session: 2 (Turbulence and Dynamos)

Title: Physics-based models for large-eddy simulations of (un)steady magnetohydrodynamic turbulence

Abstract: For Navier-Stokes turbulence, contributions to the energy cascade from e.g. vortex stretching can be identified by an exact decomposition of the energy flux [1]. This results in a quantification of the relative contributions of such effects to the kinetic energy cascade by direct numerical simulation, and provides guidance for physics-informed LES modelling. LES modelling is of particular importance for magnetohydrodynamic (MHD) turbulence due to the extreme Reynolds numbers typical for plasma flows in astrophysics and nuclear fusion [2]. The provision of better models that capture the main physical mechanisms that govern MHD cascades would therefore be a major advance for computational research in the field. For MHD LES, difficulties arise due to interactions between flow and magnetic field [2], and the unsteady nature of many fundamental problems in MHD, such as the kinematic and nonlinear dynamo. A key issue is that LES models typically underestimate the magnetic field amplification by a turbulent flow [3], for instance, the turbulent small-scale dynamo is not captured adequately by current LES models in neither its kinematic, nonlinear or saturated (i.e. statistically steady) phases. The decomposition formalism was recently extended to MHD, which led to the identification and quantification of the physical processes governing the energy cascade [4]. Here, we follow up on this work and formulate fundamental requirements of physical consistency that MHD LES model must have. Moreover, we devise and test LES models based thereon to provide new physics-informed modelling approaches for MHD turbulence and in particular the small-scale dynamo. We find that LES models that explicitly incorporate terms representative of current-sheet thinning and its back-reaction on the flow result in higher dynamo growth rates and nonlinear magnetic energy saturation levels.

References:

[1] Johnson, P. L., “Energy transfer from large to small scales in turbulence by multiscale nonlinear strain and vorticity interactions,” Physical review letters, Vol. 124, No. 10, 2020, pp. 104501.
[2] Miesch, M., Matthaeus, W., Brandenburg, A., Petrosyan, A., Pouquet, A., Cambon, C., Jenko, F., Uzdensky, D., Stone, J., Tobias, S., et al., “Large-eddy simulations of magnetohydrodynamic turbulence in heliophysics and astrophysics,” Space Science Reviews, Vol. 194, 2015, pp. 97–137.
[3] Haugen, N. E. L. and Brandenburg, A., “Hydrodynamic and hydromagnetic energy spectra from large eddy simulations,” Physics of Fluids, Vol. 18, No. 7, 2006.
[4] Capocci, D., Johnson, P. L., Oughton, S., Biferale, L., and Linkmann, M., “Energy flux decomposition in magnetohydrodynamic turbulence,” Journal of Plasma Physics, Vol. 91, No. 1, 2025, pp. E11.

Speaker: Emma Hunter

Institute: University of Glasgow

Type of presentation: Talk

Session: 2 (Turbulence and Dynamos)

Title: Lengthscale dependence of triple force balances in dynamo simulations

Abstract There has been significant progress in understanding the applicability of numerical dynamo simulations to natural dynamos in recent years as computing power has improved. This has allowed the identification of dynamo regimes relevant to Earth’s core. One way of doing so is to replicate the expected force balance of Earth's core where Coriolis, Lorentz and buoyancy forces are expected to play an important role. Recent studies have focused on the lengthscale dependence of forces and solenoidal forces, with some studies comparing the crossover lengthscale of forces with energetically relevant lengthscales. We present the lengthscale dependence of forces and solenoidal forces. Since three different forces (dependent on dynamo regime) typically govern the dynamics of dynamo simulations, we introduce a lengthscale based on a triple balance and relate this to energetically relevant lengthscales.

Speaker: Ayesha Sarwar

Institute: University of Glasgow

Type of presentation: Talk

Session: 2 (Turbulence and Dynamos)

Title: Force balances characteristic of different dynamo regimes

Abstract: The geodynamo, which sustains the Earth's magnetic field through convectively-driven fluid motion in the outer core, is a fundamental, yet complex process that continues to challenge our understanding. The fluid flow is determined by the balance of forces in the momentum equation. These forces are inherently dependent on position, time, and scale. Recent studies have investigated this complexity through scale-dependent and position-dependent analyses, with some focusing on solenoidal forces. The solenoidal forces remove the gradient components of all forces, providing a clearer picture of the first-order EFFECTS. We present three-dimensional dynamo simulations in different dynamical regimes to investigate the temporal evolution of forces and their hierarchy. We also consider solenoidal forces to gain a better view of the force hierarchy.

Speaker: Craig Duguid

Institute: Durham University

Type of presentation: Talk

Session: 2 (Turbulence and Dynamos)

Title: Dynamo action in the solar tachocline

Abstract: The leading theoretical paradigm for the Sun's magnetic cycle is an $\alpha\omega$-dynamo process (Parker 1955), in which a combination of differential rotation and turbulent, helical flows produces a large-scale magnetic field that reverses every 11 years. Most $\alpha\omega$ solar dynamo models rely on differential rotation in the solar tachocline to generate a strong toroidal field. The most problematic part of such models is then the production of the large-scale poloidal field, via a process known as the α-effect. Whilst this is usually attributed to small-scale convective motions under the influence of rotation, the efficiency of this regenerative process has been called into question by some numerical simulations (Cattaneo and Hughes 2006, Favier and Bushby 2011).

Motivated by likely conditions within the tachocline, we investigate an alternative mechanism for the poloidal field regeneration, namely the magnetic buoyancy instability in a shear-generated, rotating magnetic layer. Guided by our previous work (Duguid et al. 2023, 2024) we have used numerical simulations to investigate this mechanisms potential to operate as a solar-like dynamo.

In this talk I will present results of our simulations that demonstrate that this mechanism can indeed produce a naturally migratory dynamo with many solar-like properties.

Speaker: Susanne Horn

Institute: Coventry University

Type of presentation: **Invited Talk**

Session: 3 (Convection)

Title: Low-Rm Rotating Magnetoconvection: Linear Theory, Simulations, Experiments and Extrapolation to Planetary Core Settings

Abstract: Planetary magnetic fields are generated and sustained by turbulent rotating convection deep within their metallic interiors. This so-called dynamo process is thought to be optimal when Coriolis and Lorentz forces are approximately in balance, a state referred to as magnetostrophy. This idea is born out of linear stability analysis, which indicates that magnetostrophy facilitates the onset of convection in the form of a large-scale, stationary, inviscid mode. This single-mode hypothesis is, however, not likely to be geophysically realistic. In fact, linear theory predicts a pronounced multimodality for rotating magnetoconvection featuring a mix of different stationary, oscillatory, and wall-attached modes.

In this talk, I will revisit the classical linear stability analysis results of Elbert and Chandrasekhar and provide predictions for the regimes of rotating magnetoconvection based on the various types of possible convection modes. Additionally, I will demonstrate how these theoretical results hold up to fully non-linear low-Rm rotating magnetoconvection simulations and experiments. Finally, I will discuss what we can learn from these low-Rm rotating magnetoconvection flows about planetary core settings.

Speaker: Jo Kershaw

Institute: University of Leeds

Type of presentation: Talk

Session: 3 (convection)

Title: Dynamics of rotating convection in Earth's outer core

Abstract: Understanding the flow dynamics of the electrically conducting liquid in Earth's outer core is a crucial first step towards deciphering the mechanisms responsible for generating our planet's magnetic field. Numerical models rely on simplifying assumptions to capture the complex non-linear dynamics operating across extensive temporal and spatial scales. Complementary laboratory experiments, conducted in various curvilinear geometries, provide valuable validation for theoretical predictions by offering easier access to certain parameter ranges, such as very low Ekman numbers, which are challenging to model numerically.

This talk presents an analysis of rotating convection specifically within the tangent cylinder region, utilizing data interpolated from spherical shell simulations onto cylindrical grids. Through detailed examination of local force balances and kinetic and thermal transport properties, I highlight both similarities and differences compared to plane-layer convection bounded by sidewalls, as well as convection within the full spherical shell. Particular attention is given to the sidewall boundary and how its distinct dynamics significantly shape the overall flow characteristics.

Finally, I address how these sidewall properties might be effectively reproduced or simplified within cylindrical models, both experimental and numerical. Establishing and validating these simplified boundary conditions can enhance the comparability of future studies, ultimately deepening our understanding of convective processes in the polar regions of planetary cores.

Speaker: Matthew Lawrence

Institute: University of Leeds

Type of presentation: Talk

Session: 3 (Convection)

Title: Magnetoconvection with depth-dependent magnetic diffusivity

Abstract: A striking feature of giant planets such as Jupiter is the dramatic radial variation in electrical conductivity between the metallic hydrogen region that comprises the vast majority of the interior, and the envelope of gaseous hydrogen seen near the surface. The effects of this spatial dependence upon magnetoconvection are very physically relevant, due to the inhibiting effects of the magnetic field upon convection, and the importance of convective motion to dynamo action in giant planets. In this talk I shall share results from my analytical study of the effects of depth-dependent magnetic diffusivity upon plane-layer Boussinesq magnetoconvection. I shall begin with linear stability analysis at the onset of steady and oscillatory convection (the pitchfork and Hopf bifurcations respectively), then make a small perturbation to the magnetic diffusivity, and perform an asymptotic expansion to find exact formulae for the perturbed onset of convection, which may be compared against numerical results.

Speaker: Sonny Burrell

Institute: University of Leeds

Type of presentation: Talk

Session: 3 (Convection)

Title: Fluid instabilities in differentially rotating radiation zones with compositional gradients

Abstract: Hydrodynamic instabilities arising in differentially rotating fluids in stellar radiative zones are studied in the presence of buoyancy forces due to both thermal and chemical composition gradients. These instabilities may lead to turbulence, which can have an impact on angular-momentum transport and chemical mixing in stars.

Our local Cartesian Boussinesq model incorporates the effects of viscous, thermal and element diffusion processes. We perform a linear stability analysis of axisymmetric modes under stabilising thermal and chemical compositional stratification and investigate various parameter regimes that give rise to different instabilities in the model. We rediscover that the presence of a stabilising chemical composition gradient significantly modifies or suppresses the Goldreich-Schubert-Fricke (GSF) instability, which is a diffusive instability of differential rotation previously studied without compositional gradients (see also Knobloch & Spruit, 1983). Our model exhibits the GSF instability, an oscillatory Axisymmetric BarocliniC Diffusive (ABCD) instability, a triply diffusive instability and various adiabatic instabilities depending on the parameter regime.

We draw similarities between these instabilities and ones arising in oceanography, such as salt-fingering convection and oscillatory double-diffusive convection (Garaud, 2018). Finally, we present preliminary numerical simulations exploring the nonlinear outcome of these instabilities.

Speaker: Luke Gostelow

Institute: University of Glasgow

Type of presentation**: Invited Talk**

Session: 4 (Instabilities)

Title: Shear instability and semicircle theorems in QGSW MHD

Abstract: Shear flows are ubiquitous in the Universe and the question of their stability can have important consequences for the systems that they inhabit. In the solar tachocline, for example, shear instability has been proposed as a path to the turbulence which is needed to explain the slow radiative spreading of the tachocline (Spiegel and Zahn, 1992). Quasi-geostrophic shallow-water (QGSW) MHD (Zeitlin, 2013) is a useful model for studying this system as it includes the effects of rotation, stratification, and magnetic fields in a simple way.

Pedlosky (1987) and Hughes & Tobias (2001) have shown that it is possible to derive general bounds, semicircle theorems, on the eigenvalues of the unstable modes of shear instability from the (two-layer) QGSW and (2D) MHD equations, respectively. Here, we investigate the semicircle bounds in QGSW MHD which can be split into a spectrum of (possibly distinct) semicircles. We then consider three specific shear profiles, the vortex sheet, the Rayleigh profile, and the tanh profile, compare the modes of instability that arise, and examine their relation to the bounds provided by the semicircle theorem.

Speaker: Velizar Kirkow

Institute: University of Exeter

Type of presentation: Talk

Session: 4 (Instabilities)

Title: Shear-driven instabilities in stratified MHD with application to the solar tachocline

Abstract: In the accepted alpha-omega paradigm of the solar dynamo, it is considered that the layer located between the radiative zone below and convective zone above, known as the tachocline, is the seat of the solar dynamo. The tachocline is a thin, stably stratified shear layer in which the horizontally anisotropic flow stretches the initially dipole solar magnetic field into an azimuthal configuration, thereby increasing the magnetic field strength. This anisotropic flow is believed to be driven by shear instability and is crucial to inhibiting mixing between the radiative and convective zones either side (radially) of the tachocline. In this talk we address through linear stability analysis, weakly nonlinear theory and full nonlinear simulations how shear-driven instabilities are affected in an idealised 2D minimal model of the tachocline.

Speaker: Scott Hopper

Institute: Newcastle University

Type of presentation: Talk

Session: 4 (Instabilities)

Title: Instabilities in the Solar Tachocline

Abstract: The Sun's strong toroidal magnetic field is thought to be stored and wound up deep in its interior in a very thin shear layer known as the tachocline. The strong shear, field and stable stratification of the tachocline make it a likely host for many interesting dynamics and instabilities. We aim to explore the potential role and impact of three MHD instabilities: tearing instability, magnetorotational instability and magnetic buoyancy instability. In this talk, we pay particular attention to the tearing instability, while also briefly discussing some ongoing work regarding magnetorotational instability and magnetic buoyancy instability.

Speaker: Matt Vine

Institute: University of Leeds

Type of presentation: Talk

Session: 4 (Instabilities)

Title: Instabilities of Alfvén-Gravity Waves in Stably-Stratified MHD

Abstract: Instabilities of small-amplitude plane internal gravity waves in stably-stratified Boussinesq fluids have been attributed to resonant triad interactions. Our work addresses how such instabilities are affected by the presence of a uniform background magnetic field. With this change, the Boussinesq system permits two types of wave: pure Alfvén waves and hybrid Alfvén-gravity waves. We compute growth rates using a 1D eigenvalue solver constructed from the linearised Boussinesq MHD equations and show that the observed instabilities are related to resonant triad interactions between different combinations of these two wave types.

Speaker: Manohar Teja Kalluri

Institute: University of Exeter

Type of presentation: Talk

Session: 4 (Instabilities)

Title: Role of reconnection in Rayleigh Taylor instability

Abstract: The contact of magnetic field lines during the non-linear interaction of plumes makes magnetic reconnection a fundamental and inevitable phenomenon in magnetic Rayleigh-Taylor instability (MRTI). However, the role of magnetic reconnection on the MRTI dynamics remain largely unknown. In the current study, we investigate the importance of magnetic reconnection in the large scale dynamics including the instability evolution and energy dissipation. Comparing the non-ideal-MRTI (where reconnection is present) with an (analogous) ideal-MRTI case (where reconnection is absent), we demonstrated that reconnection, through plume merger, plays an essential role in the long-term MRTI evolution. A quantitative assessment of the role of magnetic reconnection on energy dynamics demands a statistical analysis, including the contribution from numerous reconnection events (cf. the turbulent nature of mixing layer). Towards this, a new automated 2D reconnection detection technique was developed. Using the reconnection detection algorithm, we found that the reconnection events grow temporally in a self-similar fashion. However, at any given time, the fraction of strong reconnecting current sheets is small. Consequently, the magnetic reconnection was found to be of little dynamical significance. In the context of magnetic energy dissipation, reconnection accounts for only approximately 3% of total TME dissipation. Interestingly, while the magnetic Reynolds number increases with time, the averaged reconnection rate was found to be fast and approximately constant with time. In summary, the majority of reconnection events are due to weak current sheets making the reconnection dynamics relative to dynamics from energy source less significant. However, magnetic reconnection is an inevitable and essential element of long-term MRTI evolution, without which instability stagnates.

Speaker: Wayne Arter

Institute: UKAEA, Culham Campus, Abingdon, OX14 3DB, United Kingdom

Type of presentation: Talk

Session: 4 (Instabilities)

Title: Spiking Behaviour in MHD

Abstract: MHD is one of a number of otherwise disparate topics including neuroscience, wherein is found temporal spiking behaviour. Astrophysical examples are the hard X-ray signals of recurrent solar flares, whereas in the laboratory, many plasma discharges exhibit sequences of soft disruptions and tokamaks in particular produce times series with "ELM spikes". Cross-fertilisation of ideas among different topics is enabled by a mathematical formulation of spiking as a series of abrupt and transient changes, where abrupt is taken as implying a typically exponentially fast increase[1]. "Change" is taken as happening close to instability threshold, so that ideas and approaches from equivariant bifurcation theory are applicable. Spiking behaviour in potential MHD surrogate dynamical systems[2,3] will be discussed.

[1] W. Arter. Spiking without and with blue-sky catastrophe, 2025. International Journal of Bifurcation and Chaos, submitted.
[2] W. Arter. Symmetry constraints on the dynamics of magnetically confined plasma. Physical Review Letters, 102(19):195004, 2009.
[3] W. Arter. Beyond Linear Fields: the Lie-Taylor Expansion. Proc. Roy. Soc. A, 473:20160525, 2017.

Work supported in part by EUROfusion Consortium and by UK EPSRC.

Keywords: spiking, surrogate dynamical systems, solar flare, disruption

Speaker: Muhammad Ishaq

Institute: Fluid and Complex Systems Research Centre, Coventry University, Coventry, UK

Type of presentation: Talk

Session: 4 (Instabilities)

Title: Weakly Nonlinear Analysis of Helical Magnetorotational Instability in Taylor–Couette Flow

Abstract: The magnetorotational instability (MRI) is a mechanism by which the magnetic field can destabilize a hydrodynamically stable flow of a conducting fluid without altering its velocity distribution. This instability was first discovered theoretically in cylindrical Taylor-Couette (TC) flow of perfectly conducting fluid subject to an axial magnetic field. Extensively investigated as a feasible instability mechanism of Keplerian velocity distribution in accretion disks, the MRI is thought to be behind the formation of stars and entire galaxies on the observed timescales. This hypothesis has motivated not only numerous theoretical studies but also several attempts to reproduce the MRI in the laboratory. A major challenge to such experiments is posed by the parameter known as the magnetic Reynolds number global\long\def\Rm{\mathit{Rm}}%$\Rm$, which is required to be at least ~10 for the MRI to set in. For a typical liquid metal, characterized by a small magnetic Prandtl number \global\long\def\Pm{\mathit{Pm}}% $\Pm\sim10^{-5}-10^{-6},$ this translates into a large hydrodynamic Reynolds number \global\long\def\RE{\mathit{Re}}% $\RE=\Rm/\Pm\sim10^{6}-10^{7}.$ At such large Reynolds numbers, the flow on which the MRI is expected to develop may become turbulent due to purely hydrodynamic instabilities. A solution to this problem was suggested by Hollerbach and R\"udiger (PRL 95, 124501, 2005), who discovered that a magnetorotational-type instability can take place in cylindrical TC flow at $\mathrm{Re}\sim10^{3}$ when the imposed magnetic field is helical rather than purely axial as forthe standard MRI (SMRI).
So far HMRI has been studied mostly in the linear regime which is limited to sufficiently small amplitude disurbances. Not so much is known about the non-linear evolution of HMRI which in contrast to the SMRI is an inherently resistive instability. It means that HMRI is dominated by the magnetic diffusion and thus fully captured by the so-called inductionless (low-$\Rm$) approximation which formally corresponds to $\Pm=0$. As a result, HMRI unlike SMRI affects only a limited range of hydrodynamic Reynolds numbers. Namely, besides the lower $\RE_{c}$ above which HMRI sets in, there is also an upper critical Reynolds number above which the flow re-stabilizes. This is due to the quadratically nonlinear inertia which starts to dominate over the linear Lorentz force in the $\Pm\rightarrow0$ limit. Besides being limited to relatively small hydrodynamic Reynolds numbers, the HMRI can destabilise only flows with sufficiently steep radial rotation profiles which, however, do not reach up the astrophysically relevant Keplerian velocity distribution.
Astrophysical relevance of HMRI critically depends on its ability to extend to subcritical parameter range. We address this question in the present study by carrying out a weakly non-linear stability analysis of HMRI. The Landau constants, which we compute using a highly accurate and efficient algorithm based on the Chebyshev collocation method, indicate that HMRI is a supercritical instability. We also compute strongly non-linear traveling-wave states which confirm the predictions of weakly non-linear analysis.

Speaker: Nicolas Brughmans

Institute: KU Leuven

Type of presentation: Talk

Session: 5 (Astrophysical Disks)

Title: A visual approach to MHD accretion disk instabilities

Abstract: Accretion disks around black holes have long been theorised to be turbulent in order for steady accretion flows to occur. The source of this turbulence was convincingly established by Balbus & Hawley in the 90s as an instability driven by a weak magnetic field and rotation flow shear: the Magneto-Rotational Instability (MRI). Many authors have focused on how this axisymmetric instability appears in a WKB analysis of local, Cartesian boxes moving with the background flow. Non-axisymmetric versions of the MRI, on the other hand, require a fully global approach, taking into account the curvature and radial variation of a cylindrical disk. Such a Fourier eigenmode approach to accretion disk stability can resort to MHD spectroscopy to determine the full spectrum of waves and instabilities accessible to a given disk equilibrium. Recently, rigorous MHD spectroscopy identified a new type of ultra-localised, non-axisymmetric instability in global, thin, cylindrical disks: the Super-Alfvénic Rotational Instability (SARI) (Goedbloed & Keppens, 2022, ApJL 259(2), 65). For these SARIs, a densely packed 2D region in complex eigenfrequency space contains modes that are corotating at various radii in the disk, each one localised between two Alfvénic resonances and hence insensitive to the radial boundaries. In this work, we revisit the basic mechanism behind both the MRI and the SARI through visualising the Fourier eigenmodes in time and 3D space using the Legolas code (https://legolas.science/), which calculates the Fourier spectrum of waves and instabilities for any given 3D (non-)ideal (M)HD equilibrium with variation in one dimension. We highlight how both instabilities operate through an imbalance of centrifugal, Coriolis, and magnetic tension forces, and how the polarization of the velocity and magnetic field perturbations differs importantly between thes axisymmetric and non-axisymmetric modes. In particular, the SARI polarization results in deformations of the magnetic field lines that can lead to intricate structures even in the linear regime because of the associated phase shifts. We furthermore consider disks with various equilibrium magnetic fields on top of which many linear (non-)axisymmetric modes are superposed, and determine how the resulting (linear) stresses differ. Finally, we confirm some of these properties using the finite-volume code MPI-AMRVAC (https://amrvac.org/) and follow the new SARI modes as they interact and evolve into the non-linear regime.

Speaker: Mattias Brynjell-Rahkola

Institute: Department of Applied Mathematics and Theoretical Physics, University of Cambridge

Type of presentation: Talk

Session: 5 (Astrophysical Disks)

Title: Self-sustaining dynamo states in astrophysical discs. Part 1: Solutions on the edge of chaos

Abstract: Large-scale dynamos refer to processes in which a magnetic field is generated and maintained on the system scale. This typically involves the creation of a strong toroidal field from a weak poloidal seed by differential rotation, and the subsequent feedback from the toroidal to the poloidal field by an electromotive force (EMF) due to fluctuations. In astrophysical discs with zero net-flux, the so generated toroidal field may be neutrally stable to the magnetorotational instability (MRI) such that the EMF required to close the loop stems from non-growing or decaying MRI waves. Since the EMF balances dissipation, the resulting dynamo cycles are self-sustaining and represent exact solutions to the governing equations. Of special interest in this respect are the attracting states on the basin boundary of a Keplerian shear flow known as "edge states". These can take many forms and correspond to travelling waves or periodic orbits, which are considerably simpler to analyse than full spatio-temporal turbulence. By definition, these states have a one-dimensional unstable manifold, which means that their stable manifold divide the state space into two parts. This property implies that the edge states act as mediators of turbulence and may be capable of revealing the critical magnetic and kinetic structures that are required for a large-scale dynamo process to establish. In this session, the dynamics of edge states in non-ideal magnetohydrodynamic Keplerian discs will be discussed.

Speaker: Gordon Ogilvie

Institute: DAMTP, University of Cambridge

Type of presentation: Talk

Session: 5 (Astrophysical Disks)

Title: Self-sustaining dynamo states in astrophysical discs, Part 2: Shearing waves and their electromotive forces

Abstract: The magnetorotational instability (MRI) is believed to provide sustained MHD activity and outward angular-momentum transport in astrophysical discs that are sufficiently ionized. In order to do so in the absence of an external magnetic field, the MRI must act as a nonlinear dynamo, sustaining the magnetic field that causes the instability. Significant uncertainty remains over the operation of this dynamo and its dependence on the magnetic Prandtl number. Similar considerations may apply to other dynamo processes involving magnetic instabilities such as those of Tayler or Parker involving curvature or buoyancy.

As part of a programme to understand the MRI dynamo as a nonlinear self-sustaining process (SSP, analogous to the hydrodynamic process that allows a transition to turbulence in non-rotating shear flows), we further investigate the properties of the non-axisymmetric MRI of a predominantly toroidal magnetic field in a Keplerian rotating shear flow and analyse the associated electromotive force (EMF) that can sustain the poloidal magnetic field and (in combination with orbital shear) complete a dynamo loop. In particular, we consider spatially periodic magnetic configurations of zero net flux, in which case the MRI can be interpreted either as a normal mode or as a ladder of shearing waves. For a quasi-steady dynamo process, our interest lies mainly in waves that grow (through MRI) in space rather than time because of their radial propagation away from the co-orbital region towards Alfven resonances. We describe how these waves are channeled into wave attractors around the resonant surfaces, where they are absorbed and generate an EMF.

Speaker: Chris Pringle

Institute: Coventry University

Type of presentation: Talk

Session: 5 (Astrophysical Disks)

Title: Numerical diffusivity in MHD simulations of global accretion disc dynamos

Abstract: Accretion discs - discs of (primarily) gas that form around a central mass, typically a star - are ubiquitous in astronomy. Observations have shown that energy is being dissipated in these discs at rates far greater than can be accounted for by molecular viscosity. The discrepancy has long been attributed to magneto-hydrodynamic effects. To account for the necessary rate of dissipation, the strength of these magnetic fields need to be strong, but historically simulations have only been able to produce much weaker fields. One possible explanation for this is that these simulations have been local in nature and thus unable to capture dynamics even on the size of the disc's thickness. More recent work has attempted larger, global simulations which are intended to capture the full disc. These grid-based codes have as yet only been able to generate weak fields. We present a simple model illustrating the limitations of excessive (numerical) viscosity in global models, suggesting this may be the root cause and that a more sophisticated methodology may be required.

Speaker: Paraskevi Katsiavria

Institute: Durham University

Type of presentation: Poster

Session: Poster

Title: Effects of Shear and Rotation on Convective Instabilities and Heat Transport

Abstract: Convection plays a crucial role in heat transport within astrophysical bodies. In this study, we investigate how shear flow and rotation influence convective onset and heat transport. Using a linear stability analysis, we examine the critical Rayleigh number required for onset under different shear profiles—linear and sinusoidal—and compare our findings with existing literature. We also analyse the growth rates of convective instabilities and extend our study to include rotation, both independently and in combination with shear. In the non-linear regime, we assess how these factors affect heat transport by evaluating the Nusselt number, for a given Rayleigh number. Our motivation for future work is to provide insight into the interplay between shear, rotation, magnetic fields and convection, contributing to a better understanding of astrophysical fluid dynamics.

Speaker: Sonny Burrell

Institute: University of Leeds

Type of presentation: Poster

Session: Poster

Title: Fluid instabilities in differentially rotating radiation zones with compositional gradients

Abstract: Hydrodynamic instabilities arising in differentially rotating fluids in stellar radiative zones are studied in the presence of buoyancy forces due to both thermal and chemical composition gradients. These instabilities may lead to turbulence, which can have an impact on angular-momentum transport and chemical mixing in stars.

Our local Cartesian Boussinesq model incorporates the effects of viscous, thermal and element diffusion processes. We perform a linear stability analysis of axisymmetric modes under stabilising thermal and chemical compositional stratification and investigate various parameter regimes that give rise to different instabilities in the model. We rediscover that the presence of a stabilising chemical composition gradient significantly modifies or suppresses the Goldreich-Schubert-Fricke (GSF) instability, which is a diffusive instability of differential rotation previously studied without compositional gradients (see also Knobloch & Spruit, 1983).Our model exhibits the GSF instability, an oscillatory Axisymmetric BarocliniC Diffusive (ABCD) instability, a triply diffusive instability and various adiabatic instabilities depending on the parameter regime.

We draw similarities between these instabilities and ones arising in oceanography, such as salt-fingering convection and oscillatory double-diffusive convection (Garaud, 2018). Finally, we present preliminary numerical simulations exploring the nonlinear outcome of these instabilities.

Speaker: Jamal Wachira

Institute: Northumbria University

Type of presentation: Poster

Session: Poster

Title: Compression, Impact and Rebound shocks from Coronal Rain Downflows

Abstract: Context. Cool, dense and clumpy plasma are characteristics associated with coronal rain. Understanding the thermodynamic and kinematic processes associated with it due to the thermal non-equilibrium (TNE) and thermal instability (TI) scenario can help us understand coronal heating.

Aims. We aim to study the dynamics of quiescent coronal rain and its effect on the solar atmosphere. We focus on the morphological changes observed with the coronal loop and the resultant atmospheric response due to the impact of coronal rain, commonly referred to as a 'rebound shock and flow'.

Methods. We utilise space-based data from the High-Resolution Imager in Extreme Ultraviolet (HRIEUV) of Solar Orbiter, the Atmospheric Imaging Assembly (AIA), and the Slit Jaw Imager from the Interface Region Imaging Spectrograph (IRIS/SJI) from the 1st of November 2023.

Results. During the entire coronal rain shower, the coronal loop exhibits large EUV variability and drastic morphological changes in terms of sub-structure. Coronal rain clumps with total velocities between 73 km s^{-1} and 94 km s^{-1} and cool EUV absorbing core sizes of ≈600 km and densities of ≈ 4×10^{11} cm^{-3} are seen to fall with a very strong compression occurring ahead. During the compression, we measure a low polytropic index with $\gamma = 1.08$, suggesting re-ionisation of the coronal rain plasma. The clumps carry a kinetic energy above 10^{26} erg and produce impacts seen in all EUV channels and in SJI 1400 Å. The impacts generate hot rebound flows with temperatures of $10^{6.2} - 10^{6.3}$ K and velocities of 71 − 73 km s^{-1}, which refill and reheat the loop but carry less than 10% of the clumps' kinetic energies.

Conclusions. We confirm that the TNE-TI scenario leads to large-scale EUV variability and morphological changes, mainly due to the rain's compression and impact on the lower atmosphere and the resulting rebound flows that partly refill and reheat the loop. The compression behaves isothermally due to a low polytropic index, which indicates very strong thermal conduction and the re-ionisation of hydrogen and helium of the partially ionised rain. The clumps' impact has an energy on the microflare scale, and 90% is radiated away in the lower atmosphere.

Speaker: Rose Hinz

Institute: Newcastle University

Type of presentation: Poster

Session: Poster

Title: Simulating Large-Scale Vortices in Low Prandtl, Rapidly Rotating Convections

Abstract: Back in 2016, the magnificent cyclonic structures were discovered at the polar regions of Jupiter by NASA's Juno spacecraft. While much is known about the zonal jets of Jupiter, the origin of these polar cyclones have largely remained a mystery, despite how prominent these features are. They are vast in size, long-lived, and beautifully arranged in clusters of five and eight circumpolar vortices around a larger polar vortex. This number has not changed, aside from a small, fluctuating circumpolar vortex appearing and dissipating occasionally.

The goal of our study is to explain the formation and structure of these Large-Scale Vortices (LSVs), and how these interact with the convective layer of Jupiter's atmosphere. It is believed that the Jovian atmosphere has a Prandtl number (ratio of momentum diffusivity to thermal diffusivity) of around 0.01-0.1. At this value, convective flows become oscillatory, and so part of the study is to determine whether the LSVs formed are also oscillatory.

We perform 3D, periodic local box simulations to produce rapidly rotating (fixed, high Taylor number of 1e10), incompressible, low Prandtl Rayleigh-Bénard convective flows for various values of the Rayleigh number (range of 1e5-1e8), and have currently observed four regimes: stationary flows; multiple, small, "bursting" vortices; dipolar vortices; and LSVs. It is our hope to eventually introduce a magnetic friction term, designed to mimic the Lorentz force without performing a full MHD model.
We have also discovered a new regime, dubbed "bursting", which we are currently trying to ascertain the conditions when this occurs. We have found only one case so far at Pr = 0.25, Ra = 8e5, and Ta = 1e10, but work is being done to see if this effect occurs at other values. We believe that by pursuing this, we will discover the process behind the oscillating vortex on the south pole.

Speaker: Ben Snow

Institute: University of Exeter

Type of presentation: Poster

Session: Poster

Title: Multi-species mixing in partially-ionised plasmas

Abstract: Turbulence is a fundamental process that drives mixing} and energy redistribution across a wide range of astrophysical systems. For warm (T=10^4K) plasma, the material is partially-ionised, consisting of both ionised (MHD-like) and neutral (HD-like) species. The interactions between ionised and neutral species are thought to play a key role in heating (or cooling) of partially-ionised plasmas. Here mixing is studied in a two-fluid partially-ionised plasma undergoing the shear-driven Kelvin-Helmholtz instability to evaluate the thermal processes within the mixing layer. 2D numerical simulations are performed using the open-source (PIP) code that solves for a two-fluid plasma consisting of a charge-neutral plasma and multiple excited states of neutral hydrogen. Both collisional and radiative ionisation and recombination are included. In the mixing layer, a complex array of ionisation and recombination processes occur as the cooler layer joins the hotter layer, and vice-versa. In localised areas of the mixing layer, the temperature exceeds the initial temperatures of either layer with heating dominated by collisional recombinations over turbulent dissipation. The mixing layer is in approximate ionisation-recombination equilibrium, however the obtained equilibrium is different to the Saha-Boltzmann LTE equilibrium. The dynamic mixing processes may be important in determining the ionisation states, and with that intensities of spectral lines, of observed mixing layers.

Speaker: Alban Pothérat

Institute: Coventry University, Centre for Fluid and Complex Systems

Type of presentation: Poster

Session: Poster

Title: Magnetic Taylor-Proudman Constraint explains flows into Tangent Cylinders

Abstract: Convection is the beating heart of planets such as the Earth: the rate at which the planet cools, spins-down and the dynamics of its magnetic field are all controlled by the complex interplay between buoyancy, the Coriolis force due to planetary rotation and the Lorentz force due to its magnetic field in the liquid inner core of the planet. Yet the combination of these three forces in extreme regimes makes the resulting rotating turbulent magneto-convection particularly arduous to elucidate. The main effect of rotation is to oppose fluid motion across an imaginary surface in the shape of a so-called Tangent Cylinder (TC) extruded from the equatorial perimeter of the solid inner core along the rotation direction, and up to the boundary between the liquid core and the mantle [3]. Magnetic fields on their own have a similar effect [1] and recent work suggests that intense flow within this region may participate in the planetary dynamo that sustains the Earth's magnetic field [2]. We show that when the magnetic field is close to aligned with background rotation, the classical TaylorProudman Constraint, which underpins the existence of the TC, extends into a new constraint on the combined current density of mass and charge [8]. In magneto-rotating convection, the new Magnetic Taylor-Proudman Constraint (MTPC) kinematically binds the radial and the azimuthal components of the flow at the TC boundaries. This constraint explains and quantifies the flow into the TC due to the departure from the classical Taylor-Proudman constraint incurred by the Lorentz force. Its main is consequence that when a magnetic field is present, the flow does not follow the Tangent Cylinder but can meander in and out of it. This is consistent with recent observations and numerical simulations showing that the TP constraint is violated by flows through the Earth's TC [4, 2, 5].

The theory is tested on the Little Earth Experiment (LEE) [6, 7, 8] where rotation, magnetic field and buoyancy can be controlled, and where rotating magnetoconvective patterns are visualised for the first time. LEE models the liquid core with a vessel representing the core-mantle boundary, with a cylindrical heating element placed at its centre representing the solid inner core and the buoyancy it creates. The vessel is filled with a transparent electrolyte, driven in rotation and placed inside a large magnet imitating the feedback of the Earth's magnetic field on the flow. Particle Image Velocimetry and thermistors provide us with velocity maps and local temperature measurements. We operate LEE in regimes where the flow inside the TC is either 3D or quasi-2D, and show that the time- and azimuthally-averaged radial flow near the TC boundary indeed follows the prediction of the Magnetic Taylor-Proudman constraint. When the Lorentz and Coriolis forces are comparable, the time and azimutally averaged flow exhibits a radial component through the Tangent Cylinder, of intensity consistent with the MTPC. Furthermore, LEE operates in the quasi-static MHD regime, where the induced magnetic field is too small to affect the externally imposed one (See for example [9]). We find that in this regime, the flow fluctuations too exhibit a component through the TC that is also controlled by the MTP constraint.

This constraint explains and quantifies how magnetic fields reshape rotating flows in configurations relevant to planetary interiors and in wider class of magneto-rotating flows in general.

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Speaker: Luke Gostelow

Institute: University of Glasgow

Type of presentation: poster

Session: poster

Title: On magnetoconvection and regimes in spherical dynamo simulations

Abstract: Planetary dynamo models exhibit a wide variety of possible solutions which are often characterised by their dominant force balance. In Earth's fluid outer core, a balance between the Lorentz, buoyancy, and Coriolis forces (known as a MAC - Magnetic-Archimedian-Coriolis balance) is predicted. This class of solution exhibits strong dipolar magnetic fields, whose presence can break the Taylor-Proudman constraint arising from Earth's rapid rotation. Hydrodynamic (or kinematic) simulations at low driving with otherwise similar parameters will produce velocity fields that, except near boundaries, are (essentially) invariant along the axis of rotation. As convective forcing increases in these models, this vertical anisotropy could also be broken by inertial forces; however, the solution class that then emerges (known as a CI(nertia)A balance) is generally dominated instead by kinetic energy, producing weaker multipolar magnetic fields, in stark contrast to the MAC class.

In this study, we investigate the solution space of models in which the magnetic field strength is constrained by an alternative boundary condition. We demonstrate that our magnetoconvection model still produces the known solution classes but also extends them, with intermediate solutions arising, particularly between the V(iscous)AC (which appears near onset) and MAC classes. We argue that examining the structure of the velocity and magnetic fields, as well as the force balance, in these simulations, can provide insight into which dynamo regimes and field structures can emerge in Earth and planetary contexts, when true physical parameters are still far out of the range of even the best current computers.

Speaker: Malcolm Druett

Institute: University of Sheffield

Type of presentation: poster

Session: poster

Title: Hybrid Beam-MHD models of Solar Flares

Abstract: Evaporation and condensation processes are highly dynamic in solar flares, and both can be investigated through the chromospheric spectral lines and flare ribbons. We present an investigation of these processes using a particle beam and MHD hybrid model implemented in the MPI-AMRVAC code.

Evaporation occurs from a source of chromospheric flare ribbon material. The key mechanism(s) driving the evaporation are not neatly resolved, with plausible candidates including non-thermal beams of particles, field-aligned thermal conduction, Alfven waves, and reconnection outflow jets. We present analysis of evaporations as well as downflows that form part of the flare ribbon formation (so-called “chromospheric condensations”) interpreting observed behaviours through our multi-dimensional MHD models. Through this we provide an updated schematic to interpret the formation of flare ribbons from the spectra.

Ongoing developments of our simulations are introduced (1) improving the lower atmosphere used, and the initial reconnection location (2) including asymmetry and more realistic chromospheric magnetic field parameters, (3) beam particle energy budgets and spectra informed by reconnection and particle acceleration modelling. (4) building a framework to estimate ionisation degree in the chromosphere from detailed 1D RADYN models.