# UKMHD 2021 – List of abstracts

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| Wed 19/05<br>9:30 – 10:15 | Invited talk: **Caroline Nore** (Université Paris Saclay) "Flows in liquid metal batteries"<br><br>(Joint work Wietze Herreman, Sabrina Bénard, Pedro Ziebell Ramos, Loic Cappanera, Jean-Luc Guermond, Paolo Personnettaz and Norbert Weber)<br><br>A liquid metal battery is composed of three superimposed layers of conducting fluids (light metal, molten salt, heavy alloy) and operates at high temperature (T > 400 Celsius). Traversed by intense electric currents, we can expect a variety of flows inside these cells. In this presentation, I will give an overview of our previous studies [1-6], where we combine multiphase magnetohydrodynamical simulations using our SFEMaNS code with theoretical modelling (linear and non-linear). This allows us to outline physical circumstances in which flows can cause safety hazards, or on the contrary, increase the efficiency of the battery.<br><br>1. W. Herreman, C. Nore, L. Cappanera and J. L. Guermond: Tayler instability in liquid metal columns and liquid metal batteries, J. Fluid Mech., vol. 771, pp. 79-114 (2015).<br><br>2. W. Herreman, C. Nore, J.-L. Guermond, L. Cappanera, N. Weber and G. M. Horstmann: Perturbation theory for metal pad roll instability in cylindrical reduction cells, J. Fluid Mech. 878, 598-546 (2019).<br><br>3. W. Herreman, C. Nore, P. Ziebell Ramos, L. Cappanera, J.-L. Guermond, and N. Weber: Numerical simulation of electrovortex flows in cylindrical fluid layers and liquid metal batteries Phys. Rev. Fluids 4(11), 113702 (2019).<br><br>4. W. Herreman, S. Bénard, C. Nore, P. Personnettaz, L. Cappanera and J.-L. Guermond: Solutal buoyancy and electrovortex flow in liquid metal batteries, Phys. Rev. Fluids 5(7), 074501 (28 pages) (2020).<br><br>5. W. Herreman, C. Nore, L. Cappanera and J.-L. Guermond: Efficient mixing by swirling electrovortex flows in liquid metal batteries, J. Fluid Mech., 915, A17 (24 pages) (2021).<br><br>6. C. Nore, L. Cappanera, J.-L. Guermond, T. Weier and W. Herreman: Feasibility of metal pad roll instability experiments at room temperature, accepted in Phys. Rev. Lett. (2021). |

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| Wed 19/05<br>10:15 – 10:30 | **Alex Hindle** (Newcastle) "Hotspot reversals in hot Jupiter atmospheres"<br><br>Hot Jupiters are near-Jupiter-mass exoplanets, with close-in orbits, which are expected to be tidally-locked and hosts of strong atmospheric magnetic fields. Hydrodynamic theory of hot Jupiters predicts that hotspots (equatorial temperature maxima) are always recirculated eastward (prograde) of a hot Jupiter's substellar point (point of maximal stellar irradiance); whereas 3D MHD simulations identified that magnetism could drive hotspots westward in the hottest hot Jupiters. This picture is generally corroborated by observations, which predominantly find eastward hotspots, but have also identified westward hotspot offsets in some of the hottest hot Jupiters. This talk will encompass the findings of two recently submitted papers regarding hotspot reversals in hot Jupiter atmospheres. In the first part we will identify the physical mechanism responsible for magnetically-driven hotspot reversals and discuss the physical consequences of the mechanism, including a physically-motivated reversal criterion. In the second part, we will apply this criterion to a hot Jupiter dataset and discuss the observational consequences of this process in terms observational constraints of magnetic fields strengths and testable predictions. |

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| Wed 19/05<br>10:30 – 10:45 | **Alexander Kimbley** (Leeds) "Axisymmetric instabilities of equatorial flows in planets and stars"<br><br>The large-scale circulations of the atmospheres and interiors of many planets and stars are dominated by parallel flows. The stability of these 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.<br><br>Motivated in part by observations of intense equatorial jets on Hot Jupiters, here we study instabilities of equatorial flows. We consider perhaps the simplest possible configuration of axisymmetric instabilities on an equatorial $\beta$-plane, for a flow with uniform latitudinal shear and vertical magnetic field. For linear normal modes with vertical wavenumber $m$, the dynamics are governed by a parabolic cylinder equation that yields an explicit expression for the growth rate. In the absence of magnetic field there is only a single mode, which can be identified as an inertial instability for sufficiently large $m$ and is well understood in the terrestrial atmosphere. However, with magnetic field there are two modes, one of which is always stable, while the other is always unstable, whatever the strength of magnetic field. Indeed, the maximum growth rate is found in the large field limit, where, generally, we would expect wavelike Alfvénic behaviour. We discuss to what extent the instabilities in our model can be viewed as an equatorial analogue of the MRI. |

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| Wed 19/05<br>10:45 – 11:00 | **Patrick Lewis** (Leeds) "Instabilities of a shear generated magnetic layer"<br><br>The linear stability of viscous shear flows is understood through the classic Orr-Sommerfeld equation; furthermore, Squire's theorem proves that the modes of maximum growth rate are 2D undular modes. There is an analogous but much less well-studied problem in MHD, in which a unidirectional magnetic field, varying in a transverse direction, and in the absence of a background flow, can be unstable to resistive instabilities; again, the dominant modes are 2D. Motivated astrophysically, such as by the dynamics in the solar tachocline, here we consider a self-consistent problem in which both instabilities can occur. In particular, we consider the stability of equilibrium states arising from the shearing of a uniform magnetic field by a forced transverse flow. The problem is governed by three non-dimensional parameters: the Chandrasekhar number and the flow and magnetic Reynolds numbers. In the limits of weak imposed field or weak flow, the instabilities are predominately due to either the flow or field respectively. Of particular interest is to understand how the instabilities evolve as we move through the three-dimensional parameter space between these regimes. |

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| Wed 19/05<br>11:30 – 11:45 | **James McLaughlin** (Northumbria) "MHD wave propagation in the neighbourhood of coronal null points"<br><br>Coronal null points are locations where the magnetic field, and hence the local Alfven speed, is zero. The behaviour of all three MHD wave modes, i.e. fast and slow magnetoacoustic waves and the Alfven wave, has been investigated in the neighbourhood of 2D, 2.5D and (to a certain extent) 3D magnetic null points, for a variety of assumptions, configurations and geometries. These studies contribute to our understanding of MHD wave propagation in inhomogeneous media, and this talk will review some specific findings in this area, in particular the results that have led to critical insights into reconnection, mode-coupling, and quasi-periodic pulsations. |

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| Wed 19/05<br>11:45 – 12:00 | **Giulia Murtas** (Exeter) "Plasmoid formation in partially ionised plasmas"<br><br>Plasmoid dynamics plays an important role in the onset of fast magnetic reconnection, which is responsible for driving explosive dynamics and heating in both astrophysical and laboratory plasmas. Many plasma environments of interest, like the solar chromosphere, are partially ionised. The presence of neutral components in a partially ionised plasma (PIP) and their interaction with charged particles are responsible for the development of a more complex dynamics when compared to a fully ionised plasma. Therefore, the conditions for the onset of plasmoid formation in an unstable current sheet may drastically change if neutral species are largely present in the system. Unlike the processes occurring in fully ionized plasmas, relatively little is known about how fast reconnection develops in partially ionised plasmas. In this talk, I investigate the role of partial ionization in the development of fast reconnection through the study of the coalescence instability of plasmoids, which leads to the formation of a reconnecting current sheet through plasmoid dynamics. I present 2.5D numerical simulations of coalescing plasmoids in a single fluid MHD model and a two fluid PIP model. In the PIP model plasmoid coalescence is faster than the MHD model, following the faster thinning of the current sheet and the onset of secondary plasmoid dynamics. Secondary plasmoids form in the PIP model where the effective Lundquist number S = 7.8 x 10^3 but are absent from the MHD case where S = 9.7 x 10^3. These plasmoids that form are responsible for the development of a more violent reconnection process. For a wide range of parameters, secondary plasmoids form in linearly stable conditions in the PIP model, as a consequence of the nonlinear dynamics of the neutrals in the inflow. Partial ionisation results in secondary plasmoid formation in situations that are stable to plasmoid formation in fully ionised plasmas resulting in faster and more explosive magnetic reconnection. |

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| Wed 19/05<br>12:00 – 12:15 | **Fabian Laakmann** (Oxford) "An augmented Lagrangian preconditioner for the magnetohydrodynamics equations at high Reynolds and coupling numbers"<br><br>The magnetohydrodynamics (MHD) equations are generally known to be difficult to solve numerically due to their highly nonlinear structure and the strong coupling between the electromagnetic and hydrodynamic variables, especially for high Reynolds and coupling numbers.<br>We present a scalable augmented Lagrangian preconditioner for the B-E formulation of the stationary and transient incompressible resistive MHD equations that achieves robust performance with respect to the Reynolds and coupling numbers in two dimensions and good results in three dimensions. Our approach is built upon the recent work of Farrell et al., who introduced a fluid-Reynolds-robust augmented Lagrangian preconditioner for the stationary incompressible Navier-Stokes equations. This scheme relies on a highly specialised multigrid method and we use similar ideas to treat the electromagnetic part. We extend our work to fully implicit methods for time-dependent problems which we solve robustly in both two and three dimensions. Our scheme ensures exactly divergence-free approximations of both the velocity and the magnetic field.<br>We confirm the robustness of our scheme by numerical experiments in which we consider fluid and magnetic Reynolds numbers and coupling numbers up to 10,000 for stationary problems and up to 100,000 for transient problems in two and three dimensions. |

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| Wed 19/05<br>12:15 – 12:30 | **Ben Snow** (Exeter) "MHD shocks and turbulence in the Orszag-Tang vortex"<br><br>Compressible magnetohydrodynamic (MHD) turbulence is a common feature of astrophysical systems such as the solar atmosphere and interstellar medium. Such systems are rife with shock waves that can redistribute and dissipate energy, and hence understanding the role of shocks in compressible turbulence is critical for determining the energy balance of these dynamic systems. However, automated detection and classification of shocks in turbulent systems is inherently difficult due to the highly dynamic medium. Here we present a method for detecting and classifying the full range of MHD shocks (slow, fast and intermediate) applied to the Orszag-Tang vortex. In particular, intermediate shocks (which feature a reversal in the magnetic field) appear to form most readily near reconnection sites. We present a potential mechanism that could lead to the formation of intermediate shocks in MHD systems and the role of shocks in redistributing and dissipating energy in compressible MHD turbulence. |

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| Wed 19/05<br>12:30 – 12:45 | **Andrei Igoshev** (Leeds) "Magnetic fields shape observational manifestations of neutron stars"<br><br>Neutron stars are compact remnants of supernova explosions. Some NSs have magnetic fields up to $10^{14}$-$10^{15}$ G, these are called magnetars. Magnetars show a variety of observational phenomena associated to their magnetic fields, such as bursts and giant flashes. We perform first three-dimensional simulations of the magneto-thermal evolution of NSs using a spectral MHD code. Our results show that presence of strong toroidal magnetic field in magnetars is necessary to explain their quiescent thermal emission, in particular a formation of a single hot spot. Using our thermal maps we are able to explain light curves of 10 out of 19 magnetars in quiescence. |

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| Thu 20/05<br>9:30 – 9:45 | **Tony Arber** (Warwick) "MHD from the solar surface to Earth for space weather"<br><br>The talk will describe the methods and approximations needed to predict the solar wind properties at 1 A.U. starting from solar surface magnetograms. The method adopted uses a sub-grid Alfven wave heating model to heat the corona and drive the solar wind. Comparisons with data at 1 A.U. can be used for space weather but also as a test of the assumed heating model. This may give a new way to assess theoretical corona heating models by global assessments of their effectiveness in both heating and solar wind drive using data at 1 A.U. as a test. |

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| Thu 20/05<br>9:45 – 10:00 | **Jack Reid** (St Andrews) "Curved magnetic flux tubes: supporting the spread of an MHD avalanche"<br><br>MHD avalanches involve small, intensely localized instabilities that spread across neighbouring regions in a magnetic field.<br>Cumulatively, many small events release vast amounts of stored magnetic energy.<br>Straight cylindrical flux tubes, between two parallel planes, as per the solar coronal loops modelled by Parker (1972), have been shown able to host such avalanches: an unstable flux tube can nudge those surrounding it, causing instability to proliferate through a chain of similar, reconnection-induced events.<br>On the Sun, true magnetic fields are curved, arching between different footpoints on the same photospheric plane.<br>Using three-dimensional MHD simulations, we here verify the viability of MHD avalanches within the curved magnetic geometry of a multi-threaded coronal arcade.<br>Distinct from straight cylindrical models, a torus-like instability occurs, as flux tubes displace vertically and spread instability over a region wider than the original flux tubes, but arguably more contained than that seen among straight flux tubes.<br>As a result, substantial and sustained heating is produced, contributing significantly to coronal heating. |

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| Thu 20/05<br>10:00 – 10:15 | **Thomas Howson** (St Andrews) "The effects of driving time scales on energy release in the solar corona"<br><br>The majority of models proposed for heating the solar corona fall into one of two broad categories, either AC (alternating current) or DC (direct current) heating. This dichotomy arises according to the characteristic time scales of the photospheric motions which are the source of the required energy. AC models are associated with short time scale driving and DC models with long time scales.<br><br>Despite decades of investigation, debate continues about the relative importance of each mechanism within different regions of the corona. In either case, the rate of energy injection is sensitive to both the imposed velocity profile and the form of the atmospheric magnetic field. The interaction of the driver with the evolution of the coronal field has important consequences for energy budgets. With this in mind, I will present the results of a series of numerical simulations of coronal heating in general settings. By modifying the characteristics of an imposed, random driver, I will compare the expected energy release rates and the atmospheric response for AC and DC driving. |

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| Thu 20/05<br>10:15 – 10:30 | **Prantika Bhowmik** (Durham) "Two classes of eruptive events during Solar Minimum"<br><br>During Solar Minimum, the Sun is relatively inactive with few sunspots observed on the solar surface. Consequently, we observe a smaller number of highly energetic events such as solar flares or coronal mass ejections (CMEs), which are often associated with active regions on the photosphere. Nonetheless, our magnetofrictional simulations during the minimum period suggest that the solar corona is still dynamically evolving in response to the large-scale shearing velocities on the solar surface. The non-potential evolution of the corona leads to the accumulation of magnetic free energy and helicity, which is periodically shed in eruptive events. We find that these events fall into two distinct classes. One set of events are caused by eruption and ejection of low-lying coronal flux ropes and could explain the origin of occasional CMEs during Solar Minimum. The other set of events are not driven by destabilisation of low-lying structures but rather by eruption of overlying sheared arcades. These could be associated with streamer blowouts which are often considered as potential candidates for stealth CMEs. The two classes differ significantly in the amount of magnetic flux and helicity shed through the outer coronal boundary. We additionally explore how other measurables such as current, open magnetic flux, free energy, coronal holes, and the horizontal component of the magnetic field on the outer model boundary vary during the two classes of event. This study emphasises the importance and necessity of understanding the dynamics of the coronal magnetic field during Solar Minimum. |

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| Thu 20/05<br>10:30 – 10:45 | **Peter Wyper** (Durham) "Linking flare ribbon features to fine structure in the flare current sheet"<br><br>Observations of solar flare ribbons show significant fine structure in the form of wave-like perturbations and spirals. The origin of this structure is not well understood, but one possibility is that it is related to the tearing instability in the flare current sheet. Here we study this connection by constructing an analytical three-dimensional magnetic field representative of an erupting flux rope with a flare current sheet below it. We introduce small-scale flux ropes representative of those formed during a tearing instability in the current layer, and use the squashing factor on the solar surface to identify the shape of the presumed flare ribbons. Our analysis suggests there is a direct link between flare ribbon fine structure and flare current sheet tearing, with the majority of the ribbon fine structure related to oblique tearing modes. We discuss how the nature and relative location of the tearing modes is related to spirals/waves in particular parts of the flare ribbon and conclude that fine structure in flare ribbons could potentially be used to indirectly analyse the bursty nature of flare reconnection. |

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| Thu 20/05<br>10:45 – 11:00 | **Callum Boocock** (Queen Mary University London) "The effects of oscillations and collisions of emerging bipolar regions on the triggering of solar flares"<br><br>The ability to predict the occurrence of solar flares in advance is important to humankind due to the potential damage they can cause to Earth's environment and infrastructure. It has been shown in Kusano et al. (2012) that a small-scale bipolar region (BR), with its flux reversed relative to the potential component of the overlying field, appearing near the polarity inversion line (PIL) is sufficient to effectively trigger a solar flare. In this study we perform further 3D magnetohydrodynamic simulations to study the effect that the motion of these small-scale BRs has on the effectiveness of flare triggering. The effect of two small-scale BRs colliding is also simulated. The results indicate that the strength of the triggered flare is dependent on how much of the overlying field is disrupted by the BR. Simulations of linear oscillations of the BR showed that oscillations along the PIL increase the flare strength whilst oscillations across the PIL detract from the flare strength. The flare strength is affected more by larger amplitude oscillations but is relatively insensitive to the frequency of oscillations. In the most extreme case the peak kinetic energy of the flare increased more than threefold compared to a non-oscillating BR. Simulations of torsional oscillations of the BR showed a very small effect on the flare strength. Finally, simulations of colliding BRs showed the generation of much stronger flares as the flares triggered by each individual BR coalesce. These results show that significantly stronger flares can result from motion of the BR along the PIL of a sheared field or from the presence of multiple BRs in the same region. |

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| Thu 20/05<br>11:30 – 11:45 | **Simon Lance** (Exeter) "Dissipation in rotating convection"<br><br>Convective motions are present in almost all astrophysical bodies, such as within the interiors of stars and planets, and must be sustained against any dissipative effects present. Historically, this dissipation has been treated as negligible. For the case of an incompressible fluid this is a valid assumption, however it has been shown both theoretically and numerically that for the case of highly compressible anelastic convection the amount of viscous dissipation present can in fact exceed the luminosity supplied to the fluid. The following work expands upon these findings numerically by using the python framework Dedalus to consider a layer of convective fluid contained within a Cartesian box on a tilted *f*-plane such that rotational effects can be considered. Preliminary work on the inclusion of magnetic fields and the effects of Ohmic dissipation on the overall energy balance will also be presented. |

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| Thu 20/05<br>11:45 – 12:00 | **Michael Proctor** (Cambridge) "Magnetoconvection in a Maxwell–Cattaneo fluid"<br><br>We study the instability of a Bénard layer subject to a vertical uniform magnetic field, in which the fluid obeys the Maxwell–Cattaneo (MC) heat flux–temperature relation. We extend the work of Bissell to non-zero values of the magnetic Prandtl number pm. With non-zero pm, the order of the dispersion relation is increased, leading to considerably richer behaviour. An asymptotic analysis at large values of the Chandrasekhar number Q confirms that the MC effect becomes important when QC^2 is O(1), where C is the MC number. In this regime, we derive a scaled system that is independent of Q. When QC^2 is large, the results are consistent with those derived from the governing equations in the limit of Prandtl number $p \to \infty$ with pm finite; here we identify a new mode of instability, which is due neither to inertial nor induction effects. In the large pm regime, we show how a transition can occur between oscillatory modes of different horizontal scale. For $Q \gg 1$ and small values of p, we show that the critical Rayleigh number is non-monotonic in p provided that $C > 1/6$. |

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| Thu 20/05<br>14:00 – 14:15 | **David Hughes** (Leeds) "Magnetic layering"<br><br>Magnetic buoyancy is a form of double-diffusive instability and, indeed, under certain conditions the problem can be mapped onto that of thermohaline convection. The nonlinear phenomenon of layering, or staircase formation, has been widely studied in the thermohaline context, though it is far from being fully understood. Here I shall exploit the analogy between the two systems to show how staircases can form in a system susceptible to magnetic buoyancy instability. Crucially, layering leads to enhanced transport, which may be of importance in, for example, stellar radiative zones. |

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| Thu 20/05<br>14:15 – 14:30 | **Devika Tharakkal** (Newcastle) "Non-linear magnetic buoyancy instability in galaxies"<br><br>The magnetic buoyancy instability is an extensively studied mechanism that gives insights into the dynamics of galaxies. We simulate a disk galaxy using the full non-linear MHD equations on a three-dimensional Cartesian grid using PENCIL-CODE. We study the evolution and saturation of the magnetic Rayleigh-Taylor instability. The vertically stratified system is initialized in magneto-hydrostatic equilibrium under a chosen gravitational field profile. The perturbations to the imposed initial fields are evolved according to the non-linear equations. At early times, we observe a linear growth phase, which is in agreement with previous analytical and numerical works. At later times, the system enters a non-linear state of magnetic buoyancy, which is not well understood. In this regime, we attain a steady-state for the instability and we observe systematic outflow in the system. |

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| Thu 20/05<br>14:30 – 14:45 | **Fryderyk Wilczynski** (Leeds) “Magnetic buoyancy instability in the anelastic approximation”<br><br>A horizontal magnetic field, stratified with depth, can become unstable to the instability mechanism known as magnetic buoyancy. This instability is important in an astrophysical context, being the primary candidate for the release of magnetic field from the solar interior. Magnetic buoyancy instability is inherently a compressible phenomenon: as such, its complete description is encompassed by the equations of compressible magnetohydrodynamics. However, in hydrodynamical problems, for a variety of physical, analytical or computational reasons, it is often desirable to work not with the full compressible equations but, instead, to consider simplified systems that are valid under certain constraints. Of relevance here are the simplified systems obtained under the Boussinesq and anelastic approximations.<br>Including the effects of magnetic buoyancy in the Boussinesq approximation is a subtle procedure whose important characteristic is that it imposes an ordering on the scale of the motions: the length scale in the direction of the imposed horizontal magnetic field is necessarily long in comparison with the transverse scale. On incorporating magnetic fields into the anelastic approximation, no special measures are taken to ensure that magnetic buoyancy is included consistently. However, since at least some compressibility effects have been excluded, it is by no means clear that the anelastic approximation will necessarily provide a faithful description of magnetic buoyancy instability.<br>Our aim is to look carefully at the relationship between the descriptions of magnetic buoyancy in the fully compressible and anelastic equations through a comparison of the linear stability of various magnetohydrostatic equilibria. |

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| Thu 20/05<br>14:45 – 15:00 | **Lorenzo Maria Perrone** (Cambridge) "The magneto-thermal instability in galaxy clusters"<br><br>Quantifying the transport processes in galaxy clusters is an outstanding problem that has implications for our understanding of their thermodynamic history and structure. As the dilute plasma of the intracluster medium (ICM) is strongly magnetized, heat and momentum are transported preferentially along magnetic field lines. This anisotropy triggers a new class of instabilities that destabilize the ICM. We focus on the magneto-thermal instability (MTI), which is thought to be active in the periphery of galaxy clusters. Our aim is to take a fresh look at the problem and present a broad theory that (a) explains the MTI saturation mechanism and (b) provides scalings and estimates for the turbulent heat transport, in particular. We simulate MTI turbulence with a Boussinesq code, SNOOPY which allows us to carry out an extensive sampling of the parameter space and to disentangle the effects of entropy and temperature stratification. We observe that the strength of entropy stratification sets an upper limit on the size of the turbulent eddies, and that g-modes are continuously excited at large scales by the MTI turbulence. Additionally, we note that, despite the tangled geometry of the magnetic field, a substantial fraction of heat is transported across the domain. In two dimensions, we find that the saturation regime involves a complex transfer of energy in spectral space, with energy being injected in the form of density fluctuations at small scale, and converted into kinetic fluctuations at large scales. In contrast, in three dimension this disparity of scales is absent and the turbulent motions drive a magnetic dynamo that is efficient at both high and low Pm. Finally, we validate our findings using a fully-compressible MHD code, PLUTO, and discuss potential applications of the instability to real clusters. |

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| Thu 20/05<br>15:00 – 15:15 | **John Moss** (Newcastle) “Validity of sound-proof approximations for magnetic buoyancy”<br><br>The presence of acoustic waves in compressible fluids makes the governing equations mathematically "stiff", which is a problem for computational models. Therefore, many models filter out these waves using a "sound-proof" approximation, such as the Boussinesq, anelastic or pseudo-incompressible models. We assess the accuracy of each of these approximations for describing magnetic buoyancy under a range of physical conditions relevant to the solar interior. By comparing the linearised equations for a general sound-proof model with those of the fully compressible model, we derive a number of constraints which must be satisfied for the sound-proof model to capture the leading-order behaviour of the fully compressible system. We discuss the physical significance of these constraints with reference to existing sound-proof models. |

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| Thu 20/05<br>15:15 – 15:30 | **Jane Pratt** (Georgia State University and Exeter) "Diffusion and dispersion in anisotropic magnetohydrodynamic turbulence"<br><br>Magnetohydrodynamic (MHD) turbulence structured by a large-scale magnetic field is an essential aspect of interstellar or interplanetary plasmas. Here we investigate diffusion and dispersion in anisotropic MHD turbulence. We adopt the Lagrangian viewpoint, the natural point of view to study diffusion, and construct statistics based on the trajectories of Lagrangian tracer particles. From the motions of these tracer particles, we produce Lagrangian statistics such as single-particle diffusion, two-particle dispersion, and velocity autocorrelations. We also demonstrate new Lagrangian statistics developed to understand anisotropic turbulent dispersion. Simulation results will be presented that are performed using grid sizes up to $2048^3$. Diffusion and transport processes in turbulent plasmas constitute fundamental astrophysical problems; a clear understanding of these processes is needed in order to produce improved theoretical models for the diffusion and transport of energetic particles, including cosmic rays. |

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| Fri 21/05<br>9:30 – 10:15 | Invited talk: **Julien Aubert** (IPG Paris) "Modelling the geodynamo, a strongly (time)-scale separated MHD system"<br><br>Natural convective dynamos such as the geodynamo operate in a regime of strong separation between key temporal and spatial scales. Scale separation of any kind is a stumbling block for numerical simulations. The exact nature of the dynamical regime in such systems has therefore remained unclear. In this talk, I will present some of the advances obtained over the past decade thanks to improvements in computational power and the development of physically relevant approximations. The new models have clarified the nature of the force balance within the asymptotic regime of rapid rotation relevant to natural systems. This balance, termed QG-MAC, comprises a leading order quasi-geostrophic (QG) equilibrium between the Coriolis and pressure force, followed at the next order by an equilibrium between the Lorentz force, buoyancy force and the ageostrophic part of the Coriolis force (the MAC balance). The QG-MAC balance prescribes a typically large scale of injection of convective power into the magnetic field, with this energy being Ohmically dissipated at a smaller, albeit not impossibly small scale because of the moderate level of magnetic turbulence. It is therefore possible to design a system of reduced spatial complexity that preserves this energy flow across scales, and this has proven to be an efficient way to obtain models operating well within the asymptotic regime and close to the conditions of natural dynamos. These approximated models again demonstrate the robustness of the QG-MAC balance, a corollary of which is the obtention of solutions approaching a Taylor state to a high degree of accuracy. While the QG-MAC balance is responsible for the slow, inertialess evolution of the convective dynamo on core overturn time scales, deviations to this balance are necessarily balanced by inertia, which comes several orders of magnitude below the QG-MAC forces. The response generally takes the form of Alfvén waves with propagation velocities largely exceeding the convective velocities. Reducing the spatial complexity of the system therefore does not harm the temporal complexity, as the models reproduce the time scale separation observed for instance in the geomagnetic signal and provide an explanation for short-timescale geomagnetic jerks co-existing with slower convective variations. |

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| Fri 21/05<br>10:15 – 10:30 | **Colin Hardy** (ETH Zurich) "The inherent instability of axisymmetric magnetostrophic dynamo models"<br><br>Recent studies have demonstrated the plausibility of constructing magnetostrophic dynamo models, which describe the slowly evolving background state of Earth's magnetic field in the absence of inertia and viscosity. Here we explore the properties of steady, stable magnetostrophic states as a leading order approximation to the slow dynamics within Earth's core. For the case of an axisymmetric magnetostrophic system driven by an alpha-effect, we show that there are only four steady states in general, all of which reside in simple dipole or quadrupole symmetries. Importantly, in all but the most weakly driven cases, a non-symmetric initial magnetic field never converges to these states. Despite this instability, we also show that there are a plethora of instantaneous solutions that are quasi-steady. For the Earth, this work suggests that the background state can never be stably steady. Furthermore, we show that the magnetostrophic state, while defined on the slow magnetic diffusion timescale of 50ka, exhibits dynamics on much shorter timescales of 1-10ka which overlaps significantly with more rapid inertia-driven processes. |

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| Fri 21/05<br>10:30 – 10:45 | **Stephen Mason** (Newcastle) "Magnetoconvection with a uniform axial magnetic field in a rotating spherical shell"<br><br>We are studying the effect of an imposed uniform axial field on Boussinesq convection in a rotating spherical shell. The Fortran pseudo-spectral code Parody has been used to run simulations with increasing magnetic field strength $B_0$, as well as varying Rayleigh and Ekman numbers. I will discuss the effects of the imposed field on the flow at the onset of convection, and how this changes with increasing Rayleigh number. Convection is more vigorous for intermediate values of $B_0$, where the magnetic and rotational forces are balanced - in these cases, a modified version of the Taylor-Proudman theorem is found to hold. Magnetically-modified Rossby waves have also been observed at onset, with slower frequency than the thermal Rossby waves. We find that strong zonal flows form for intermediate values of $B_0$ for Rayleigh numbers a few times critical. Finally, I will discuss how the imposed field affects the efficiency of the heat transfer. |

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| Fri 21/05<br>10:45 – 11:00 | **Stefano Maffei** (Leeds) "Plesio-geostrophy for the Earth's core"<br><br>Although geodynamo models are fundamental in advancing our understand of the complex dynamics taking place in the Earth's outer core, their computational cost prevents them from accessing the extreme parameters that we think describe the Earth's core dynamics. This limitation is particularly severe in data assimilation frameworks where geomagnetic field observations (particularly those from the latest Swarm satellite mission) are combined with geodynamo models.<br><br>An attractive alternative is to adopt the columnar approximation, sometimes called the quasi-geostrophic approximation, known to be appropriate in the presence of very rapid rotation on short timescales. The spirit of this approximation is to reliably describe the dynamics of the core via 2-dimensional variables, thus dramatically reducing the computational costs of equivalent 3-dimensional simulations. However, the 2-dimensional description of the magnetic forces acting on the flow has proven mathematically challenging.<br><br>Here we present a new formalism, termed plesio-geostrophy (PG), that involves axial averages of various magnetic and buoyancy-related quantities (each of which is a type of moment) and magnetic fields on control surfaces. The resulting equations are a set of 17 self-consistent partial differential equations, each in two-dimensions. We further validate the PG equations by considering the problem of diffusion-free normal modes in a full sphere. In the regime of small Lehnert number (quantifying the strength of magnetic to inertial forces), we show that these modes can provide a good description of full 3D modes, capturing their essential features. These results suggest that PG should provide a sound basis for geomagnetic data assimilation. |

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| Fri 21/05<br>11:30 – 11:45 | **Daniel Johnson** (University of Central Lancashire) "Numerical simulation of sunspot rotation"<br><br>The study of sunspot rotation is a mature subject that has been investigated both theoretically and observationally. Sunspot rotation is recognised as an important mechanism for depositing energy into the Sun's atmosphere. An understanding of the characteristics of this energy input is important, because this energy may be transported and stored in the solar atmosphere, effectively enhancing the free magnetic energy above sunspots and in the larger systems in which they reside. This additional source of free energy may provide, or contribute to, the energy budget for space weather phenomena like solar flares, coronal mass ejections and solar energetic particles. We present a parametric investigation that deconvolves the complex real-world phenomenon of sunspot rotation into its components. This project uses the Lare3D numerical code to model an idealised rotating sunspot; the influence this rotating sunspot has on itself and its environment is investigated. Key physical parameters of the sunspot and its environment are varied to determine the mechanisms responsible for energy production, transport and release. A unique feature of this work is that the penumbra forms an important component of our idealised sunspot. Preliminary results find that the penumbra makes a significant contribution to the storage and transport of energy injected by sunspot rotation |

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| Fri 21/05<br>11:45 – 12:00 | **Breno Raphaldini** (Durham) "Magnetic winding in observations of solar active regions"<br><br>Magnetic helicity is an invariant of the ideal MHD equations and is used as a diagnostic tool in the analysis of magnetic fields in active regions. Here, we explore an associated quantity, the winding number, that measures the degree of knotedness of a magnetic field configuration. The winding has the advantage of not being strongly concentrated in regions of strong magnetic field, and therefore it is more sensitive to changes in the topology of the magnetic field in the whole domain. The winding has been shown to be an efficient tool in MHD simulations of magnetic field emergence, now we present evidence of its efficacy in observations. We present the analysis of a few active regions using the winding and compare it with the analysis of helicity. In summary, we find that the winding is able to detect structural changes in the magnetic field more effectively than the helicity, and suggest that it can be used as an alternative predictive tool for eruptive events in active regions. |

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| Fri 21/05<br>12:00 – 12:15 | **Anthony Yeates** (Durham) "Revisiting Taylor relaxation"<br><br>Turbulent magnetic relaxation is an important candidate mechanism for coronal heating and some types of solar flare. By developing turbulence that reconnects the magnetic field throughout a large volume, magnetic fields can spontaneously self-organize into simpler lower-energy configurations. We are using resistive MHD simulations to probe this relaxation process, in particular to test whether a linear force-free equilibrium is reached. Such an end state would be predicted if one assumes the classic Taylor hypothesis: that the only constraints on the relaxation come from conservation of total magnetic flux and helicity. In fact, a linear force-free state is not reached in our simulations, despite the conservation of these total quantities. Instead, the end state is better characterised as a state of (locally) uniform field-line helicity.<br>(joint work with Alexander Russell and Gunnar Hornig) |

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| Fri 21/05<br>12:15 – 12:30 | **Simon Candelaresi** (Glasgow) "Vortex reconnection and the role of topology"<br><br>We perform numerical experiments of relaxing and reconnecting vortex braids. While these braids have no net kinetic helicity, they are topologically non-trivial. Similar experiments with magnetic braids in MHD have shown a non-trivial relaxation behavior that resulted in two distinct twisted flux tubes. Here we observe the same separation behavior. Furthermore, we show analytically and experimentally that the presence of unsigned kinetic helicity poses a lower bound for the enstrophy of the system, similar to the realizability condition in MHD. Lastly, even the kinetic energy appears limited from below by the unsigned helicity, although we do not have an analytical explanation for this. |

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| Fri 21/05<br>12:30 – 12:45 | **David MacTaggart** (Glasgow) "Magnetic winding: what is it and what is it good for?"<br><br>In this talk, I will present a renormalization of magnetic helicity called magnetic winding. Magnetic winding provides different and clearer information about field line topology compared to magnetic helicity. Further, it can be calculated in practice just as easily as magnetic helicity. As well as laying the theoretical foundations of magnetic winding, I will present applications of it to solar magnetic flux emergence and show how magnetic winding can provide clear signatures of the magnetic topology of emerging fields. |

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| Fri 21/05<br>14:00 – 14:15 | **Adrian Barker** (Leeds) "New results on the interaction between tidal flows and turbulent convection"<br><br>The interaction between tidal flows and turbulent convection in stars and planets is often considered important for tidal evolution of the orbits and spins of close binary stars and short-period extrasolar planets. Its efficiency for fast tides has however long been controversial, when the tidal frequency exceeds the turnover frequency of convective eddies. I will describe some new results on this problem based on a careful analysis of all of the energy transfer terms that is verified by both Boussinesq and anelastic numerical simulations in spherical shell geometry. These simulations directly simulate the interaction between tidal flows and convection. I will also review the latest results from local Cartesian and global spherical Boussinesq simulations of the same problem that show that convection can act like an effective viscosity which decays quadratically with tidal frequency for fast tides. Finally, I will discuss the astrophysical consequences of this work. |

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| Fri 21/05<br>14:15 – 14:30 | **Aurélie Astoul** (Leeds) "Non-linear simulations of tides in an adiabatic convective shell"<br><br>In close two-body astrophysical systems, like binary star or Hot-Jupiter systems, tidal interactions often drive dynamical evolution on secular timescales. Many host stars feature a magnetised and convective envelope, and such layer may also be present in the envelopes of giant gaseous planets. Tidal flows that are generated there, due to the tidal potential of the companion, are dissipated by viscous friction mechanisms which lead to redistribution of angular momentum in the convective shell. In the tightest systems, non-linear effects are likely to have a significant impact on the tidal dissipation and change the zonal flows, triggering differential rotation, as demonstrated in the hydrodynamical study of Favier+2014.<br><br>In this context, we investigate how the addition of non-linearities affect the tidal flow properties, and the energy and angular momentum balances, thanks to 3D non-linear simulations of a convective and incompressible shell using the pseudo-spectral code MagIC. In this talk, we will mostly present<br>the hydrodynamical case which is intended as a preliminary study before adding a magnetic field. Unlike the above-mentioned study, we have chosen a body forcing where the equilibrium tide (the quasi-hydrostatic tidal flow component) acts as an effective force to excite tidal inertial waves, while using stress-free boundary conditions. With this more realistic set-up, we show new results for the amplitude of the energy stored in zonal flows, and how it affects tidal dissipation and angular momentum evolution. |

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| Fri 21/05<br>14:30 – 14:45 | **Anna Guseva** (Leeds) "Nonlinear dynamos: a data-driven approach"<br><br>Organized, large-scale magnetic fields are frequently encountered in the Universe, from planets and stars to accretion disks and galactic clusters. It is widely accepted that these fields are created through dynamo action, which is supported by turbulent motions of conducting fluid inside astrophysical objects and opposed by the Ohmic dissipation. This process involves two competing dynamo mechanisms: the generation of small-scale filamentary fields stretched by the smallest turbulent eddies, and the generation of the large-scale field through net interaction of the turbulent flow and field fluctuations. The large-scale and the small-scale dynamos compete nonlinearly, and the final, steady-state magnetic field of an astrophysical object would depend on the nonlinear interactions of the two mechanisms, as well as on their nonlinear saturation.<br><br>A lot of insight on these nonlinearities comes from direct numerical simulations (DNS) of the dynamo flows. However, DNS are usually far from the realistic parameter regimes of astrophysical flows, as the governing parameter, magnetic Reynolds number, is extremely large. In addition, a DNS of a dynamo produces fluctuating velocity and magnetic fields with energy spread over a continuous range of scales, so that any definition of a field scale depends on the chosen averaging or filtering procedure. In order to construct a fully nonlinear reduced-order basis for dynamo flows, and uncover the underlying nonlinear interactions, we employ here an alternative, data-based approach. In essence, it enables the extraction of dynamically relevant spatial components (modes) and their temporal evolution from DNS flow snapshots. This is achieved with Dynamic Mode Decomposition (DMD), a method that approximates the underlying nonlinear dynamics of a system with a Koopman-like linear model. As a benchmark problem, we construct a simplified system of partial differential equations, based on Parker's dynamo waves and involving both slow, large-scale and fast, small-scale dynamics. We will show how DMD can identify the large-scale and small-scale modes and their interaction in the resulting multi-scale field. Finally, we will apply the DMD method to a dynamo flow driven by helical forcing and shear. |

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| Fri 21/05<br>14:45 – 15:00 | **Kuan Li** (Leeds) "Reservoir Computing for Prediction of Fluid and MHD systems"<br><br>In this talk, we use a data-driven approach to investigate MHD systems. The solar dynamo and the geodynamo systems operate in extreme dynamical regimes and directly computing these systems is either numerically expensive or far beyond the reach of the modern supercomputing power. Therefore it is of interest to examine how data-driven techniques can be used both for prediction and parameterisation of unresolved scales. Here we consider reservoir networks (rNN) which are nonlinear, recursive and sparse systems and ideal candidates for approximating the dynamical systems of a large number of degrees of freedoms. The dynamical systems approximated by rNN can be solved very efficiently.<br><br>We present the results of the study of a simple ODE model of nonlinear dynamo action using the reservoir network. We find that the rNN can be trained to predict the evolution of the convective dynamo system up to the order of 10 Lyapunov time. We also present an effective hybrid strategy for improving the predictability if current observations are complemented by the trained reservoir neural network. |

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| Poster session<br>Thu 20/05<br>12:00 – 12:45 | **Azza Algatheem** (Exeter) "Jets and instabilities in forced magnetohydrodynamic flows"<br><br>It is known that forced fluid flows can be unstable to the formation of large-scale jet motions. These instabilities can occur in the presence of the beta-effect, called zonostrophic instability, and has implications for observed geophysical and astrophysical systems. However, in astrophysical bodies such as the Sun, magnetic fields are also present, and how these fields change the stability is still not understood. We consider Kolmogorov flow with a magnetic field. Our initial results focus on the beta=0 regime, where the hydrodynamic flow is unstable when the critical Reynolds number above the square root of two and the dimensionless viscosity down the one over the square root of two. We studied the MHD case for both vertical and horizontal fields and determined the stability. In the case of the vertical field, we are found the adding a magnetic field suppresses the original instability. By comparison, two different types of instability appear in the case of the horizontal field, which produces a more complicated structure of the eigenfunction than the vertical field because of the flow advecting field lines. The results will be relevant to understanding the effect of magnetic field on the stability of flows in the solar tachocline. |

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| Poster session<br>Thu 20/05<br>12:00 – 12:45 | **Craig Duguid** (Newcastle) "Convective turbulent viscosity acting on equilibrium tidal flows"<br><br>Tidal interactions are important in driving spin and orbital evolution in various astrophysical systems such as hot Jupiters, close binary stars and planetary satellites. However, the fluid dynamical mechanisms responsible for tidal dissipation in giant planets and stars remain poorly understood. One key mechanism is the interaction between tidal flows and turbulent convection which is thought to act as an eddy viscosity ($\mathbf{v}_E$) dampening the large scale tidal flow. The efficiency of this mechanism has long been debated, particularly in the regime of fast tides, when the tidal frequency ($\boldsymbol{\omega}$) exceeds the turnover frequency of the dominant convective eddies ($\boldsymbol{\omega}_c$). The pioneering work of Zahn (1966) proposed that $\mathbf{v}_E \sim \boldsymbol{\omega}^{-1}$ while Goldreich & Nicholson (1977) found $\mathbf{v}_E \sim \boldsymbol{\omega}^{-2}$.<br><br>Using hydrodynamical simulations we investigate the dissipation of the large scale (non-wavelike) equilibrium tide as a result of its interaction with convection. Our approach is to conduct a wide parameter survey in order to study the interaction between an oscillatory background shear flow, which represents a large-scale tidal flow, and the convecting fluid inside a small patch of a star or planet. We simulate Rayleigh-Bénard convection in this Cartesian model and explore how the effective viscosity of the turbulence depends on the tidal (shear) frequency.<br><br>We will present the results from our simulations to determine the effective viscosity, and its dependence on the tidal frequency in both laminar and weakly turbulent regimes. The main result is a new scaling law for the frequency dependence of the effective viscosity which has not previously been observed in simulations or predicted by theory and occurs for shear frequencies smaller than those in the fast tides regime. These results have important implications for tidal dissipation in convection zones of stars and planets, and indicate that the classical tidal theory of the equilibrium tide in stars and giant planets should be revisited. |

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| Poster session<br>Thu 20/05<br>12:00 – 12:45 | **Parag Gupta** (Glasgow) "Effects of shell thickness on cross-helicity generation in convection-driven spherical dynamos"<br><br>Rotating thermal convection is ubiquitous within the interiors and the atmospheres of celestial bodies. These fluid regions contain plasma or metallic components so vigorous convection drives large-scale electric currents and produces the self-sustaining magnetic fields characteristic of these celestial objects. Here, we are interested in understanding the relative importance of the **α**-effect (helicity) and **γ**-effect (cross-helicity) as a function of the thickness of the convective rotating spherical shell. There are two regimes of dipolar dynamos, those with dominant mean components (MD, "Mean Dipole") and those with dominant fluctuating components (FD, "Fluctuating Dipole"). We investigate the importance of the **α**-effect and **γ**-effect in these regimes across a range of shell thickness. The simulations are based on the Boussinesq approximation of the governing nonlinear magnetohydrodynamic equations with stress-free velocity boundary conditions. Two distinct branches of dynamo solutions are found to coexist in direct numerical simulations for shell aspect ratios between 0.25 and 0.6. The **α**-effect found to be dominant in the case of the geodynamo, while both **α**- and the **γ**-effects are comparable in the case of the solar global dynamo. This is due to differences in shell aspect ratio and dynamo regime: the solar dynamo is a thin-shell fluctuating dynamo while the geodynamo is a thick-shell mean-dipole dynamo. |

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| Poster session<br>Thu 20/05<br>12:00 – 12:45 | **Konstantinos Karampelas** (Northumbria) "Oscillatory reconnection of a 2D magnetic X-point for systems with different base temperatures"<br><br>The propagation of magnetoacoustic waves about a 2D magnetic X-point has revealed the existence of oscillatory reconnection, which is a series of horizontal and vertical current sheets with associated changes in magnetic connectivity. Oscillatory reconnection has been proposed as a wave-generation mechanism to explain some of high-speed, quasi-periodic outflows/jets in the solar atmosphere, as well as one possible physical mechanism behind quasi-periodic pulsations (QPPs). In this study we expand the results of McLaughlin et al. (2009) by performing a parameter study over a wide range of base temperatures. We solve the full set of 2D MHD equations for a magnetic X-point with the use of the PLUTO code, with explicit resistivity included. Through a nonlinear wave, we initiate the collapse of the X-point into a current sheet, initiating oscillatory reconnection for systems of different base temperatures. We study the evolution of plasma beta and its effects on the oscillatory process. By increasing the base temperature of the system, we see that both the amplitude and the period of the oscillating current density profile change. Finally, we will discuss how thermal conduction affects the temperature evolution of our systems, and by extension the final non-potential state of our systems. |

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| Poster session<br>Thu 20/05<br>12:00 – 12:45 | **Oliver Rice** (Durham) "Equilibrium solutions of the magneto-frictional model with solar wind outflow"<br><br>When modelling the coronal magnetic field using the magneto-frictional model it is important to consider the effect of the solar wind, which is most significant near the outer boundary of the computational domain. We show that under certain conditions it is possible to find a stable magnetic field with an imposed solar wind outflow velocity. Together with a suitable boundary condition on the surface of the sun this field can be used as an initial condition for the evolution of magneto-frictional code. This contrasts with the standard approach of using a potential (current-free) field as an initial condition, which is not initially compatible with an imposed outflow velocity. By assuming axisymmetry, we can find semi-analytic equilibria for an arbitrary outflow speed. As this speed increases, we observe that the magnetic field lines `open-up' and become more radial. |

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| Poster session<br>Thu 20/05<br>12:00 – 12:45 | **Liam Watts** (Exeter) "The scaling laws of flux expulsion"<br><br>Flux expulsion is a process that transports magnetic fields within the solar interior. If we impose a weak magnetic field onto a convective eddy, the field will be advected by the flow, causing spiral wind up until the gradients between adjacent field-lines are large enough that magnetic reconnection occurs. The result is that magnetic flux is expelled from the central region of the eddy. We are considering the two main cases for flux expulsion: the kinematic case, where the field is sufficiently weak that it has no effect on the flow and the dynamic case, where the magnetic field is sufficiently strong that it will cause a back-reaction onto the flow. A sufficiently large Lorentz force is able to turn off flux expulsion. By introducing flows with separatrices, we are able to obtain new scaling laws to those found in theory for the kinematic and dynamical case. |