## Titles and Abstracts : UKMHD2022, June 9-10 meeting

### Magnetic fields and the Dynamics of Giant Planet Interiors

Prof. C. Jones
University of Leeds (UK)

### Impact of nonlinearities for tidal flows in convective shells

Aurélie Astoul & Adrian Barker
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In close exoplanetary systems, tidal interactions drive orbital and spin evolution of planets and stars over long timescales. Tidally-forced inertial waves (restored by the Coriolis acceleration) in the convective envelopes of low-mass stars and giant gaseous planets contribute greatly to the tidal dissipation when they are excited and subsequently damped (e.g. through viscous friction), especially early in the life of a system. These waves are known to be subject to nonlinear effects, including triggering differential rotation in the form of zonal flows. In this context, we investigate how nonlinearities affect the tidal flow properties, thanks to new 3D hydrodynamic and magneto-hydrodynamic nonlinear simulations of tides, in an adiabatic and incompressible convective shell. First, we show to what extent the emergence of differential rotation modifies the tidal dissipation rates, from prior linear predictions. In particular, nonlinear self-interactions of tidal inertial waves can trigger different kind of instabilities and resonances between the waves and the newly created sheared flow, when the tidal forcing is strong enough or the viscosity low enough.  Secondly, we present the first nonlinear numerical analysis of tidal flows in a magnetised convective shell. One main effect of magnetic field in our model is to mitigate the zonal flow triggered by the nonlinear self-interaction of inertial waves. The consequences for tidal flows are important, since the interaction between waves and the zonal flow in nonlinear hydrodynamical simulations is the main cause of significant changes in tidal flow response, compared to linear predictions for a uniformly rotating body.

### Exploring the Origin of Stealth Coronal Mass Ejections with Magnetofrictional Simulations

Prantika Bhowmik, Anthony Yeates, Oliver Rice
Durham University (UK)

Coronal mass ejections (CMEs) are among the most energetic events originating from the Sun. Various surface and low coronal features have been regarded as critical elements in predicting the occurrence of CMEs. However, a significant fraction of CMEs exhibit no such detectable signatures and are known as “stealth CMEs”, which often cause unpredictable geomagnetic disturbances. Theoretical and observational studies aiming to understand the physical mechanism behind stealth CMEs have identified coronal streamers as potential sources. In this work, we show that such streamer-blowout eruptions – which do not involve the lift-off of a low-coronal magnetic flux rope – are naturally produced even in the quasi-static magnetofrictional model for the coronal magnetic field. We have first reproduced the stealth CME event observed during 1 – 2 June 2008. Secondly, we show that the magnetofrictional model predicts the occurrence of repeated eruptions without clear

low-coronal signatures from such arcades; instead, overlying magnetic field lines erupt repeatedly when sufficiently sheared by differential rotation. A two-dimensional parameter study with a two-dimensional magnetofrictional model shows that such eruptions are robust under variation of the parameters. The footpoint shearing primarily determines the eruption frequency. This suggests that magnetofrictional models could, in principle, provide early indication – even pre-onset – of stealth eruptions, whether or not they originate from the eruption of a low-coronal flux rope.

## Modelling and detecting oscillations in MHD simulations of reconnection in solar flares

P K. Browning, M.Gordovskyy, J Stewart and C Smith
University of Manchester (UK)

Quasi-periodic pulsations in flare emission may provide important information about the underlying energy release process. We describe the application of MHD simulations to investigate how reconnection, in the absence of external oscillating driving, may naturally generate oscillations, and we forward-model observable emissions. Firstly, we consider 3D MHD simulations of a flaring twisted coronal loop with multiple reconnection sites, allowing for inclusion of a population of non-thermal particles produced at current sheets. We forward-model the thermal and non-thermal gyro-synchrotron emission and find that oscillations with a range of periodicities can be present, and we compare these predictions with observed QPPs in microwaves. Secondly, a more generic MHD model is explored, with reconnection at a single current sheet formed as two twisted flux ropes merge, in order better to understand how reconnection can drive waves. We find the reconnection is oscillatory, and that this also generates wave-like disturbances, mainly in azimuthal flow and radial magnetic field, which propagate away from the reconnection site.

## The role of coherent structures in hydromagnetic dynamos: a wavelet-based approach

Prof. Paul Bushby
Newcastle University (UK)

Turbulent dynamos are present in many astrophysical systems. We consider dynamo action in turbulent flows that contain coherent structures, focusing particularly upon the role that these structures play in determining the growth rate of the dynamo. One approach to this problem is to apply Fourier filtering to the velocity field (Tobias & Cattaneo 2008) to identify the dominant scales of motion in the dynamo. However, localised coherent structures are not always well-represented by such filtering schemes, with information distributed across many Fourier components. An alternative approach is to use wavelets, which are better suited to describing such localised coherent structures. We will present simulations of 2.5D dynamo action, using flows derived from 2D hydrodynamic turbulence. The flows are filtered in wavelet space, retaining only those wavelet coefficients whose magnitude exceeds a certain threshold; only a small fraction of the relevant modes must be kept in order to ensure the retention of the dominant coherent structures in the flow. We will describe the extent to which the dynamo growth rate for these filtered flows depends upon the filtering threshold, comparing our findings with comparable Fourier-based filters. Based upon this comparison of these two filtering approaches, we will discuss the extent to which a wavelet-based approach could be used to better understand astrophysical dynamos.

## The role of magnetic helicity in stabilising magnetic cavities in the intergalactic medium

Simon Candelaresi, Fabio Del Sordo
Glasgow University (UK)

Observations have shown that above some galactic disks there exist hot under-dense bubbles in the intergalactic medium. Due to their low density, they rise and seem to survive for tens of millions of years. However, the Kelvin-Helmholtz instability should lead to a break up at a much shorter time scale.

We test if an internal magnetic field with helicity can stabilize the bubbles. This is motivated by the realizability condition that imposes a lower bound for the magnetic energy in presence of magnetic helicity. We compare the non-magnetic case with two cases with a internal helical magnetic field. Both magnetic fields have the same energy, but different helicities by a factor of 4. We run numerical simulations that clearly show that a highly helical magnetic field can stabilize the bubbles for several of tens of millions of years. The energy required is much lower than for a stabilizing external magnetic field.

## The mean electromotive force arising from shear driven magnetic buoyancy and rotation

Craig Duguid, Paul Bushby, Toby Wood
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Since the pioneering work of Parker 1955, the leading theoretical paradigm for the Sun's magnetic cycle has been an alpha-omega dynamo process, in which a combination of differential rotation and turbulent, helical flows produce a large-scale magnetic field that reverses every 11 years. The most problematic part of this model is the production of large-scale poloidal field – the alpha effect – which is usually attributed to small-scale convective motions under the influence of rotation.

We revisit the original Parker model, in which the differential rotation in the solar tachocline generates a strong toroidal magnetic field, which then becomes buoyantly unstable. We study this magnetic buoyancy instability to determine whether, in the presence of rotation, it can by itself provide the necessary regenerative effect.

We present results of simulations of a local, rotating (with aligned and tilted rotation vectors), fully compressible model in which an imposed vertical shear winds up an initially vertical background magnetic field which ultimately becomes buoyantly unstable. In particular, we measure the resulting turbulent electromotive force (EMF) where we are primarily interested in the component in the direction of the mean magnetic field, as required for a Parker-like dynamo to operate.

For sufficiently rapid rotation, we find that the mean EMF has a significant component in the direction of the mean magnetic field, as required for a Parker-like dynamo to operate. Our results suggest that magnetic buoyancy contributes directly to the generation of large-scale poloidal field in the Sun.

**Zonostrophic instabilities in MHD Kolmogorov flow**

Azza Al Gatheem, Andrew Gilbert and Andrew Hillier
University of Exeter (UK)

Our work is based on Kolmogorov flow, first studied by Meshalkin & Sinai (1961), which is a sinusoidal velocity field with a two-dimensional, unidirectional profile, u= (0, sin x). This is maintained by an external force in a viscous fluid. It is known that this kind of fluid flow is unstable to large-scale jet motions, known as "zonostrophic instability", and this has recently been studied in a variety of settings both numerically and analytically. For example, Manfroi & Young (2002) have incorporated a beta-effect corresponding to a gradient of background planetary vorticity. Jet formation through instability can occur in the presence of the magnetic field and has implications observed in geophysical and astrophysical systems Hughes et al.(2007).

In our study we incorporate a mean magnetic field, which can be x-directed ("horizontal") or y-directed ("vertical") in our two-dimensional system and gives an MHD version of Kolmogorov flow. In a basic equilibrium state magnetic field lines are straight for the case of vertical field and sinusoidal for horizontal field with an additional component of the external force balancing the resulting Lorentz force. As the basic state is independent of the y-coordinate we use Fourier analysis to study waves of wavenumber k in the y-direction, using the methods of classical stability theory and numerical solution of eigenvalue problems. We present some results using analytical approximations in the limit of k to 0, that is for large-scale jets. We also present some nonlinear results making use of the package Dedalus.

**Shear Instabilities in Quasi-Geostrophic MHD**

Luke Gostelow
University of Leeds (UK)

The rotating shallow-water equations, originally derived in the context of the terrestrial atmosphere, have recently been extended to include a magnetic component in order to model the dynamics of e.g. the solar tachocline. In the rapidly rotating limit, we then obtain an analogue to thequasi-geostrophic equations. By modelling the differential rotation of the solar interior as a zonal shear flow, we will investigate the effects of rotation and a magnetic field on shear instabilities in this system. We will derive necessary conditions for instability and also bounds on the phase speed and growth rate of these instabilities. We will then consider the vortex sheet profile for which analytic solutions can be derived. Finally, we will examine the hyperbolic tangent shear profile. Here we will use a numerical method to obtain solutions and also show that in some limiting cases we can approximate this profile as the vortex sheet.

**Thermal Rossby Waves within the Sun's Convection Zone**

Bradley W. Hindman & Rekha Jain
University of Colorado Boulder (USA) & University of Sheffield (UK)

We explore how thermal Rossby waves propagate within the gravitationally stratified atmosphere of the Sun's convective zone. Under the conditions of rotationally constrained dynamics, we derive a local dispersion relation for atmospheric waves in a fully compressible stratified fluid. This dispersion relation describes the zonal and radial propagation of acoustic waves and gravito-inertial waves. Thermal Rossby waves are just one class of prograde-propagating gravito-inertial wave that manifests when the buoyancy frequency is small compared to the rotation rate of the star. From this dispersion relation, we identify the radii at which waves naturally reflect and demonstrate how thermal Rossby waves can be trapped radially in a waveguide that permits free propagation in the longitudinal direction. We explore this trapping further by presenting analytic solutions for thermal Rossby waves within an isentropically stratified atmosphere that models a zone of efficient convective heat transport. We find that within such an atmosphere, waves of short zonal wavelength have a wave cavity that is radially thin and confined within the outer reaches of the convection zone near the equator. The same behavior is evinced by the thermal Rossby waves that appear at convective onset in numerical simulations of convection within rotating spheres. Finally, we suggest that stable thermal Rossby waves could exist in the lower portion of the Sun's convection zone, despite that region's unstable stratification. For long wavelengths, the Sun's rotation rate is sufficiently rapid to stabilize convective motions and the resulting overstable convective modes are identical to thermal Rossby waves.

**The thermo-resistive instability for hot Jupiter atmospheres**

A. W. Hindle, Dr P. J. Bushby, & Prof. T. M. Rogers
Newcastle University (UK)

Hot Jupiters are near-Jupiter-mass exoplanets in close-in orbits, which have large day-night temperature differentials and hence extreme day-night conductivity variations. Consequently, they may play host to a number of variable-conductivity magnetohydrodynamic phenomena, including the thermo-resistive instability.

The onset of a thermo-resistive instability in hot Jupiter atmospheres is examined using idealised three-dimensional magnetohydrodynamic simulations, with temperature-dependent magnetic diffusivity.
The thermo-resistive instability has been predicted to emerge in hot Jupiter atmospheres, though it has not previously been simulated explicitly. We find that the instability emerges due to strong variable-conductivity-driven induction ($\eta$-induction) in the simulated atmospheres. Our simulations show that the instability causes extreme Ohmic heating where it emerges, which acts to temper magnetic field amplification from the $\eta$-induction. Understanding the thermo-resistive instability and measuring the degree of the intense Ohmic heating that it generates is likely to be essential in understanding whether magnetism can explain hot Jupiters' overly-large radii. Such explanations have been hypothesised, but are not consistent with measurements from leading MHD simulations of hot Jupiter atmospheres.

**Magnetic Buoyancy and the Anelastic Approximation**

Prof. D. Hughes
University of Leeds (UK)

**Three-dimensional numerical simulations of ambipolar diffusion in neutron stars.**

Andrei Igoshev & Rainer Hollerbach
University of Leeds (UK)

We perform three-dimensional numerical simulations of ambipolar diffusion in core of neutron stars in the single fluid MHD approximation. We assume that evolution proceeds through a series of magneto-hydrostatic quasi-equilibrium states. Our simulations cover core and crust and include Ohmic decay. We concentrate on weak-coupling regime which is typical for core temperature below 5e8 K. We found that axisymmetric initial configuration develops non-axisymmetric component at the timescale of ambipolar diffusion . The ambipolar diffusion leads to development of a strong current sheet in the deep crust which heats the crust and could release up to 1e29-1e30 erg/s over Myr timescale.

**Instabilities of Equatorial Jets in Planetary Atmospheres**

Alexander Kimbley
University of Leeds (UK)

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.

Motivated in part by observations of intense equatorial jets on Hot Jupiters, here we study instabilities of equatorial flows. We consider axisymmetric instabilities in a uniformly stratified fluid on an equatorial $\beta$-plane, for a zonal jet centred close to the equator in the presence of a vertical magnetic field. For linear normal modes with vertical wavenumber $k$, 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 $k$ and is well understood in the terrestrial atmosphere. The significant influence of magnetic field is that it can lead to instabilities in parameter regimes that are hydrodynamically stable. We discuss to what extent these instabilities can be viewed as an equatorial analogue of the MRI.

**Joint Instabilities of Sheared Flows and Magnetic Fields**

Patrick Lewis, David Hughes, Evy Kersale
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Shear flows and magnetic fields are ubiquitous in astrophysical bodies such as stars and accretion discs. Furthermore, the interaction between flows and magnetic field plays a key role in the dynamics of plasma fusion devices. Typically, the flows and magnetic field are both sheared, and it is therefore a problem of fundamental importance to understand the instabilities that may occur in such a system.

In the absence of magnetic field, the linear stability of a viscous sheared flow is governed by the Orr-Sommerfeld equation; this is one of the classic problems of hydrodynamics. At the other limit, there are somewhat analogous instabilities of a fluid of finite electrical conductivity containing a static sheared magnetic field. These are related to the classical tearing modes that have received considerable attention in both the astrophysical and plasma physics literature.

In general though, the fluid flow and the magnetic field will both be important players. Previous studies have investigated configurations which have served as models for systems such as the magnetotail and solar surges. While these investigations have been fruitful, the prescription of the basic field and flow, while physically motivated, have been chosen somewhat arbitrarily. It is therefore of interest to consider the instability problem within this more general framework.

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 opposite limits of parameter space, we recover the predictions of the aforementioned classical problems. As we move through this three-dimensional parameter space, a range of interactions are possible: We demonstrate the stabilisation of a purely hydrodynamic instability through the magnetic field, show the existence of a joint instability outlining the physical mechanisms at play, and demonstrate that under certain conditions, hydrodynamically-stable parallel shear flows lead to instability growth rates that exceed those of static tearing modes. To conclude, we elucidate the consequences of considering the linear stability of an evolving background state and show that a quasi-static approach may not be meaningful. In these circumstances, it therefore becomes essential to perform a stability analysis of a time-varying basic state.

## Direct statistical simulation: an alternative approach to turbulence

Kuan Li, J.B. Marston, Steven Tobias
University of Leeds (UK)

Direct Statistical Simulation (DSS) is a new theoretical and numerical framework for describing and solving turbulent fluid and MHD problems in the paradigm of statistical physics and fluid dynamics. DSS seeks to approximate the spatio-temporal evolution of the probability distribution of these systems by a set of low-order statistical equations, namely cumulant equations. The low-order cumulants are smooth in space and therefore require many fewer degrees of freedom for numerical computations than those required for direct numerical simulation (DNS). DSS is hence expected to access turbulent dynamical systems in the extreme dynamical regimes beyond the reach of DNS. However, conventional approaches in DSS also suffer a significant challenge, known as the curse of dimensionality, which usually strongly limits the application of this method up to the 2nd-order cumulant only.

We present a series of recent theoretical and numerical developments in DSS, that successfully bypass the curse of dimensionality of the conventional approaches and enable us not only to describe these problems with an extreme efficiency but also to yield the numerical solutions of the low-order cumulant equations with a high statistical accuracy up to the 3rd order. Furthermore, we have simplified the statistical closure, CE2.5, suited for computing the third-order cumulants. In this presentation, we demonstrate the effectiveness and advantages of this new method by solving two representative turbulent problems a 2D turbulent fluid dynamical system driven by a Kolmogorov force and a turbulent plasma model, modified Hasegawa-Wakatani in 2-dimensions. We believe that our approach in DSS is now directly applicable for solving 3D turbulent fluid dynamical and MHD problems in extreme dynamical regimes.

**Magnetoconvection in a rotating spherical shell in the presence of a uniform axial magnetic field**

S.J.Mason, C.Guervilly, G.R.Sarson
Newcastle University (UK)

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 had been used to run simulations with increasing magnetic field strength, as well as varying Rayleigh and Ekman numbers. Here I will discuss the effects of varying the magnetic Prandtl number. I will first focus on the effects of the imposed field on the flow at the onset of convection. For a magnetic Prandtl number of unity, we found a decrease in the critical parameters at intermediate values of the imposed magnetic field strength. When varying the magnetic Prandtl number, we find further changes in the critical parameters, with different field strengths required to influence the onset of convection. I will also discuss the changes seen with increasing Rayleigh number, where we have observed a negative induced axisymmetric poloidal magnetic field in most of the domain.

**Quasi-static Magnetoconvection in a Rotating Tangent Cylinder**

Alban Pothérat & Kélig Aujogue
Coventry University (UK)

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 in the liquid region of the planet. Yet the combination of these three forces and the extreme regimes in which they operate makes the resulting rotating magnetoconvection particularly arduous to elucidate. The main effect of rotation is to oppose fluid motion across an imaginary surface in the shape of a cylinder 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[1]. Recent work suggests that intense flow within this region may participate in the planetary dynamo that sustains the Earth's magnetic field[2]. Yes the mechanisms driving the flow within this region are yet to be understood.

We present The Little Earth Experiment[3,4], an original device where all these ingredients are present, and where rotating magnetoconvective patterns are visualised for the first time. The principle of the experiment is to model the liquid core with a hemispherical vessel representing the core-mantle boundary, with a cylindrical heating element placed at its centre modelling 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 thermoucouples provide access to velocity maps and local temperature measurements.

We find that similarly to non-magnetic rotating convection [4], mildly supercritical convection in these conditions features bulk modes made of thin plumes and wall modes sitting on the TC's boundary. both interact nonlinearly as criticality increases.The Lorentz force, however alters the impermeable condition at the TC's boundary, resulting in a radial flow there. This effect reshapes the global flow inside the TC, and in particular the azimuthal thermal wind that occupies the entire volume.

**Eruptivity Criteria for Two-dimensional Magnetic Flux Ropes in the Solar Corona**

Oliver Rice and Anthony Yeates
Durham University (UK)

We apply the magneto-frictional approach to investigate which quantity or quantities can best predict the loss of equilibrium of a translationally-invariant magnetic flux rope. The flux rope is produced self-consistently by flux cancellation combined with gradual footpoint shearing of a coronal arcade which is open at the outer boundary. This models the magnetic field in decaying active regions on the Sun. Such a model permits two types of eruption: episodic small events caused by shearing and relaxation of the overlying arcade, and major eruptions of the main low-lying coronal flux rope. Through a parameter study, we find that the major eruptions are best predicted not by individual quantities or the previously proposed 'eruptivity index' but by thresholds in the ratios of squared rope current to either magnetic energy or relative magnetic helicity. We show how to appropriately define the latter quantity for translationally-invariant magnetic fields, along with a related eruptivity index that has recently been introduced for three-dimensional magnetic fields.

**Towards minimal seeds for the geodynamo**

Calum S. Skene, Florence Marcotte, and Steven M. Tobias
University of Leeds (UK)

Linear instability of a conducting fluid to magnetic perturbations can cause a magnetic field to grow large enough such that it can modify the velocity field via the Lorentz force. If this interaction between the magnetic field and the fluid results in a self-sustaining magnetic field, it is termed an "essentially kinematic" dynamo. However, even for flows without this instability dynamo solutions can exist if the initial magnetic field is such that it reaches a self-sustaining state, with the resulting "essentially nonlinear" dynamo being a sub-critical solution. Whether or not the magnetic field reaches such a dynamo solution is then critically dependent on two factors; the initial energy of the perturbation, and its structure. Finding these initial magnetic fields is of interest for understanding various physical phenomena such as the geodynamo, where one route to the Earth's magnetic field is via a subcritical initial seed. Here, a finite amplitude magnetic field may be responsible for breaking the strong constraints placed on hydrodynamic flows by rotation and lead to efficient dynamo action. In this talk we will discuss how optimisation techniques, that have recently been shown to be successful in uncovering subcritical dynamo solutions [1], can be used to help determine these initial geodynamo seeds. Special attention is given to finding minimal seeds, that is magnetic fields with the smallest energy that result in subcritical dynamos.
[1] P. M. Mannix, Y. Ponty & F. Marcotte, "A systematic route to subcritical dynamo branches" PRL, in press (arXiv:2112.11376)

**The effect of axisymmetric and spatially varying equilibria on magnetoacoustic waves in magnetic flux tubes**

Samuel Skirvin, Viktor Fedun, Suzana Silva, Gary Verth
KU Leuven (Belgium) and University of Sheffield (UK)

In the context of the solar atmosphere, magnetohydrodynamic (MHD) waves are routinely observed and are believed to contribute to its energy budget. Realistic analytical models are required such that they can be combined with observational data to determine the sub resolution properties of local solar atmospheric plasma, which may not be measured directly. Here, we investigate the properties of magnetoacoustic waves under non-uniform equilibria in a cylindrical geometry, using a previously developed numerical eigensolver. Case studies investigating the effect that a radially non-uniform plasma density, modelled as a series of Gaussian profiles, have on the properties of different MHD waves, are presented. For all cases the dispersion diagrams are obtained and spatial eigenfunctions calculated which display the effects of the equilibrium inhomogeneity. We show that as the equilibrium non-uniformity is increased, the radial spatial eigenfunctions are affected and extra nodes introduced, similar to the previous investigation of a magnetic slab. Furthermore, we show that when the plasma density is sufficiently non-uniform, the azimuthal component of the displacement perturbation increases with increasing inhomogeneity, causing a distortion of the waveguide boundary where the perturbations are enhanced. Finally, 2D and 3D representations of the velocity fields are shown which may be useful for observers for wave mode identification under realistic magnetic waveguides with ever increasing instrument resolution.

**Corrugation instability in partially ionised slow-mode shocks**

Ben Snow, Andrew Hillier
University of Exeter (UK)

A magnetohydrodynamic (MHD) shock front can be unstable to the corrugation instability, which causes a perturbed shock front to become increasingly corrugated with time. An ideal MHD parallel shock (where the velocity and magnetic fields are aligned) is unconditionally unstable to the corrugation instability, whereas the ideal hydrodynamic (HD) counterpart is unconditionally stable. For a partially ionised medium (for example the solar chromosphere), both hydrodynamic and magnetohydrodynamic species coexist and the stability of the system has not been studied. Here we present numerical simulations of the corrugation instability in two-fluid partially-ionised shock fronts that investigate the stability conditions, and compare the results to HD and MHD simulations. Our simulations consist of an initially steady 2D parallel shock encountering a localised upstream density perturbation. In MHD, this perturbation results in an unstable shock front and the corrugation grows with time. We find that for the two-fluid simulation, the neutral species can act to stabilise the shock front. A parameter study is performed to analyse the conditions under which the shock front is stable and unstable. We find that for very weakly coupled or very strongly coupled partially-ionised system the shock front is unstable, as the system tends towards MHD. However, for a finite coupling, we find that the neutrals can stabilise the shock front, and produce new features including shock channels in the neutral species. We compare the perturbation wavelength to the finite-width of the shock to comment on the stability of chromospheric slow-mode shocks.

**Tidal dissipation as a result of the interaction between the elliptical instability and convection in Hot Jupiters**

Nils B. de Vries, Adrian J. Barker, Rainer Hollerbach
University of Leeds (UK)

Tidal dissipation results in numerous effects, among which is circularisation of the

orbit and spin-orbit synchronisation. One of the processes that is thought to be responsible for this is the elliptical instability. This instability is predominantly expected in exoplanets close-in to their host star, which feature strong tidal deformations, i.e. Hot Jupiters. The interaction of the elliptical instability with convection has been studied using simulations in a local box model. Two results were obtained: 1) Bursts of efficient tidal energy transfers originating from the elliptical instability are present in simulations with convection, however they can be overshadowed by the convection as the Rayleigh number (a measure of how strongly convection is driven) increases. If the ellipticity (i.e. tidal amplitude) is low enough and the Rayleigh number high enough, the bursts disappear completely. This results in a steady rate of energy injection from the tidal flow, for which the time-averaged value is larger than that of the bursts produced by the elliptical instability. The steady energy injection is consistent with an $\epsilon^2$ scaling and is a function of the Rayleigh number, indicating that this is likely due to turbulent viscosity of convection acting on the tidal flow. For larger tidal amplitudes (or low enough Rayleigh numbers), we also find evidence compatible with the $\epsilon^3$ scaling for the energy transfers obtained in prior simulations without convection. The maximum inferred tidal amplitude for a Hot Jupiter is $\epsilon=0.06$ (for WASP 19b), and the Rayleigh numbers in planetary interiors are likely much higher than the ones achieved in our simulations. Hence, we expect Hot Jupiters to be in the regime of steady energy injection, assuming these results hold for realistic values of the Rayleigh number. 2) The bursts of the elliptical instability are capable of enhancing the heat transport, even in stably stratified surface radiative layers.

### MHD flow on a sphere: semi-circle rules and the clamshell instability

C. Wang, Andrew Gilbert and Joanne Mason
University of Exeter (UK)

We study the instability of 2-dimensional magnetohydrodynamics (MHD) on a sphere using analytical methods. The basic flow consists of a zonal differential rotation and a toroidal magnetic field. The semicircle rules that prescribe the possible domain of the wave velocity in the complex plane for general flow and field profiles have been derived. We find the magnetic field may increase the radii of semicircles through the spherical geometry, which does not happen in Cartesian geometry. We then undertake an analytical study on the `clamshell instability', which features field lines on two hemispheres tilting in opposite directions (Cally 2001, Sol. Phys. vol. 199, pp. 231-249). We derive an asymptotic solution for the instability problem in the limit of weak shear of the zonal flow. We show that when the zonal flow is solid body rotation, there exists a neutral mode that tilts the magnetic field lines and makes them rotate, which we refer to as the `tilting mode'. A weak shear of the zonal flow excites the critical layer of the tilting mode, which reverses the tilting direction to form the clamshell pattern, and induces instability. The asymptotic solution provides insights to the property of instability for general flow and field profiles.

### Flux expulsion in shallow-water magnetohydrodynamics

Liam Watts. Supervisors: Andrew Gilbert and Joanne Mason
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Flux expulsion a process where an electrically conducting vortex winds up a magnetic field via the induction equation, and flux is expelled from a region of closed streamlines. The kinematic regime is when the magnetic field is sufficiently weak that it has a negligible effect on the flow and this regime has been well documented. More recently, the dynamical regime with stronger magnetic fields has been investigated and in this case the flow will produce a back-reaction through the Lorentz Force. For sufficiently large magnetic fields, flux expulsion doesn't occur and the flow produces Alfven waves that propagate along the magnetic field lines. Here, we will introduce flux expulsion to shallow-water MHD and compare this to the 2D incompressible case. We will look when this process occurs and the role that the height field plays.

**Does intermittent interchange reconnection launch switchbacks into the solar wind?**

P. F. Wyper, A. K. Higginson, C. R. DeVore, S. K. Antiochos,
D. I. Pontin, R. B. Scott, S. Masson, T. Pellegrin
Durham University (UK)

The origins of magnetic switchbacks have been hotly debated since the first perihelion of Parker Probe revealed their abundance within the near-Sun solar wind. One idea that has attracted attention is that switchbacks could be formed by interchange reconnection in the solar corona. In this work we test this hypothesis using adaptively-refined, high-resolution, 3D MHD simulations of interchange reconnection occurring at a pseudostreamer. Surface motions are used to stress the null of the pseudostreamer, which initially collapses into a Sweet-Parker-like current layer before becoming violently unstable to plasmoid formation. We find that plasmoids repeatedly form and are ejected from the layer leading to a continual modulation of the solar wind within the stalk of the pseudostreamer. This modulation takes the form of many small-scale torsional Alfven wave-like perturbations but crucially does not include any reversals of the radial field component. Our study therefore suggests that although intermittent interchange reconnection at pseudostreamers could be a source of significant variability, it is unlikely to launch switchbacks directly into the solar wind.

## Posters

**Magnetized turbulent-laminar dynamics in shear flows**

L. Cope, S. M. Tobias, J. B. Marston
University of Leeds (UK)

Turbulence is ubiquitous in nature, however, the characterisation of the transition that gives rise to turbulence in shear flows is yet to be accomplished. Intermittency is a defining feature of the initial onset of turbulence in wall-bounded flows, in which chaotic regions, often in the form of bands or spots, coexist and compete with laminar motion. Connections between the behaviour of this laminar-turbulence transition have been made with both the dynamics of excitable media in addition to predator-prey dynamics, although it is hard to differentiate between these two models since there is only one control parameter, namely the Reynolds number. In this study, we attempt to unfold this problem by adding a magnetic field, the presence of which suppresses the excitability of the medium, making the turbulence less intermittent and modifying the form of the bands. By considering the low magnetic Reynolds number quasi-static approximation, we introduce a second control parameter, the Hartmann number, thereby enabling this transition to be explored in a systematic manner.

We study the idealised shear between stress-free boundaries driven by a sinusoidal body force. Known as Waleffe flow, the turbulence in this system has been shown to

demonstrate both qualitative and quantitative agreement to that in the interior of plane Couette flow. This system is further reduced by exploiting the absence of boundary layers in order to construct a model that uses only four Fourier modes in the shear direction, thus substantially reducing the computational cost of simulations whilst retaining the fidelity of the essential physics. Conclusions are drawn based on a series of carefully designed numerical simulations.

### Global magnetic helicity in convection-driven spherical dynamos

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Magnetic helicity is a measurement of field line entanglement weighted by magnetic flux and is a fundamental constraint in both ideal and resistive magnetohydrodynamics. On the Sun and other stars, magnetic helicity density at the stellar surface is used as a proxy for the internal behavior of the dynamo driving the global magnetic field. We study the behaviour of the global relative magnetic helicity in several spherical dynamos. The results shed light on the role played by magnetic helicity in dynamos and indicate how observations can be used to interpret global dynamo behaviour.

### Electric excitation of Alfven waves at low magnetic Reynolds number

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Alfven waves are magneto-mechanic waves which consists of an oscillation of both magnetic and momentum disturbances propagating along magnetic field lines. They were first theorised by Alfvén in 19421 and discovered seven years later by Lundquist2. After 70 years of research, due to the difficulty of reproducing these waves in laboratory, the knowledge of their dynamics remains elusive. In particular, their relevance at the low magnetic Reynolds numbers typical of most liquid metal experiments is controversial.
Here, a revisited version of the Flowcube device, initially developed by Klein3, is used to investigate these waves in liquid metal (GalInstan) under a magnetic field of up to 10 Tesla. The originality of the setup is to force the wave by injecting an AC current through an array of electrodes located at the top and bottom plates of its rectangular vessel (also called Hartmann plates). This current interacts with the magnetic field to induce azimuthal Lorentz forces and thus generate a vorticity oscillation centred on top of each electrode in use. To observe the waves, these plates are equipped with electric potential probes symmetrically placed on both plates.
This study addresses three key questions. The first one is whether electrically driven Alfven waves can be sustained at low magnetic Reynolds number, ie when the magnetic diffusion term prevails over the advective one. Second, how, and in which regimes do they compete with the diffusive nature of the Lorentz force, which, under the current paradigm, prevails at low Rm. Last, can Alfven waves reach a nonlinear regime, relevant to nonlinear processes occurring in plasmas and astrophysical flows? We will show preliminary results indicating that the Lorentz force may indeed underpin wave propagation at low Rm, whilst retaining its diffusive nature and that a nonlinear behaviour may ensue provided the waves are sufficiently excited.

### Evolution of the magnetic Rayleigh-Taylor instability under varying magnetic field strengths

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The magnetic Rayleigh Taylor instability (RTI), where a lighter fluid accelerates into heavier fluid under the influence of gravity and in the presence of magnetic field, is a ubiquitous phenomenon in astrophysics. It has been found to occur in a wide range of astrophysical systems from stars to supernova to accretion discs. The linear problem has been well-studied, but for the non-linear problem, while numerous studies have previously been carried out in hydrodynamic RTI, very little work has been performed in magnetic RTI. In our current research, we aim to study the mixing by the non-linear RTI using 2D, Cartesian, incompressible numerical simulations. The study uses a spectral code called Dedalus. We present results from our preliminary study where we vary the magnetic field strength between 10^{-2}*B_c to B_c, where B_c is the critical magnetic field strength, to determine the influence of magnetic fields on the mixing rate. In the long run, the study aims to probe into some fundamental questions like the possible self-similar development in the turbulent magnetic RTI.

**Geometrical interpretations for gauge transformations of helicities of open magnetic fields**

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Magnetic helicities play a crucial role in magnetohydrodynamics as an ideal invariant. It is, however, well known that they are not invariant under gauge transformations of the magnetic vector potential, except for fields that have no normal components at the boundaries. Starting from the Helmholtz-Hodge decomposition for vector fields on surfaces, we prove that a particular choice of gauge, known as (restricted) toroidal-poloidal (TP) gauge or the winding gauge (introduced by Prior & Yeates (2014)), provides a geometrical interpretation of helicities for open magnetic fields as the pairwise winding of magnetic field lines, in both Cartesian and spherical shell domains. Also, we argue that all admissible gauge transformations correspond uniquely to diffeomorphisms of the underlying space explained in terms of the field line windings, while the TP or winding gauge can be understood as the canonical choice as the identity element of the relevant diffeomorphism group.