# 2016 UK MHD –

## National Conference on Geophysical, Astrophysical and Industrial Magnetohydrodynamics

Glasgow, 12 and 13 May 2016

University of Glasgow | School of Mathematics & Statistics

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## — Programme —

A long version of this programme including abstracts is available online at
http://www.gla.ac.uk/schools/mathematicsstatistics/events/conferences/ukmhd2016.

**— Thursday, 2016-05-12 —**

### Welcome and Registration

*9:00 – 10:25* Arrival, registration, set-up of posters. Refreshments available.

*10:25 – 10:30* PROF ADRIAN BOWMAN
Head of School Welcome message

### Invited Lecture

*Chairperson:* Keke Zhang

*10:30 – 11:10* PHILIPPA BROWNING
Relaxation modelling and MHD simulations of energy release in kink-unstable coronal loops

Twisted magnetic flux ropes are fundamental building blocks of the solar coronal magnetic field and provide a reservoir of free magnetic energy which can be released in large-scale solar flares – as well as in smaller, but much more frequent, nanoflare events associated with coronal heating. We first describe 3D MHD simulations of individual twisted solar coronal loops in which magnetic reconnection is triggered by the ideal kink instability, extending earlier models in cylindrical geometry to more realistic coronal loop geometries. Magnetic reconnection, both within the loop and between the loop and the surrounding field, dissipates magnetic energy. Test-particles can be incorporated into the model, allowing prediction of energetic particle acceleration, and forward-modelling of the observational signatures of both thermal and non-thermal plasma. We then show how instability in a single unstable loop may trigger reconnection with stable neighbouring loops, releasing the stored energy in these loops and leading to an "avalanche" of heating events. Thus, an avalanche is demonstrated in a MHD model, as previously proposed in more idealised Cellular Automaton models. For both individual and interacting loops, the field relaxes towards a lower-energy equilibrium which is well-approximated as linear force-free field. We present a relaxation model for merging coronal loops, and show how this may be used to predict the energy release and heating for a wide parameter space.

### Session 1: Solar Applications I

*Chairperson:* Alan Hood

*11:10 – 11:25* TONY ARBER, *C. Brady*
Simulations of Alfven wave driving of the solar chromosphere - efficient heating and spicule launching.

By driving Alfven and kink waves into an expanding flux tube we demonstrated that with a Poynting flux on $2 \times 10^7$ erg/s/cm$^2$ we can reproduce a heating profile broadly consistent with the mid to upper chromosphere. The heating mechanism is through ponderomotive coupling of Alfven waves to shock and it is the shocks which dissipate and heat. These same shocks also produce jets similar to spicules (Type-I).

*11:25 – 11:40* BEN SNOW, *G. Botha, J. McLaughlin, A. Hillier*
Onset of 2D reconnection in the solar photosphere, chromosphere and corona

Numerical simulations have been performed to analyse the onset of 2D magnetic reconnection at different atmospheric heights in the sun. These heights were chosen to be the photosphere, chromosphere and corona. The photosphere is almost neutral while the corona is almost fully ionised. In the solar chromosphere, the plasma is partially ionised which introduces Cowling resistivity that acts perpendicular to the magnetic field. Taking as initial condition a Harris current sheet in equilibrium, a Gaussian-shaped velocity driver is specified far from the current sheet which creates a localised wave that triggers the 2D reconnection event. The start-up of the reconnection is analysed in the three atmospheric regions.

*11:40 – 11:55* ANDREW HILLIER, *Shinsuke Takasao, Naoki Nakamure*
Investigating slow-mode MHD shocks in a partially ionised plasma

The role of slow-mode MHD shocks in magnetic reconnection is of great importance for energy conversion and transport, but in many astrophysical plasmas the plasma is not fully ionised. Here we use numerical simulations to investigate the role of collisional coupling between a proton-electron, charge-neutral fluid and a neutral hydrogen fluid for the one-dimensional Riemann problem that mimics reconnection shocks. The initial stages of the evolution are characterised by an over-pressured neutral region that expands with characteristics of a blast wave. In the later stages, the system tends towards a self-similar solution where the main drift velocity between the ions and neutrals is concentrated in the thin region of the shock front. Because of the nature of the system, the neutral fluid is overpressured by the shock when compared to a purely hydrodynamic shock, which results in the neutral fluid expanding to form the shock precursor. Once it has formed, the thickness of the shock front is proportional to ionisation fraction to the exponent -1.2, which is a smaller exponent than would be naively expected from simple scaling arguments. One interesting result is that the shock front is a continuous transition of the physical variables of sub-sonic velocity upstream of the shock front to a sharp jump in the physical variables followed by a relaxation to the downstream values for supersonic upstream velocity. We will present some information about the role of the frictional heating from the collisional coupling in the shock system.

*11:55 – 12:10* JAMES THRELFALL, *J. E. H. Stevenson, C. E. Parnell, T. Neukirch*
Particle dynamics at reconnecting magnetic separators

I will report on results of test particle orbit calculations in the vicinity of reconnecting magnetic separators. Magnetic separators are special magnetic field lines which are thought to be likely sites of 3D magnetic reconnection; whether or not this reconnection may be responsible for particle acceleration remains an open question. I will discuss how our work has moved from using a simplified kinematic separator reconnection model to include recent high resolution MHD simulations of separator reconnection. I will compare the results of both approaches, present and analyse particle orbit trajectories, and deduce a simple relationship between the final energy range of particle orbits and model dimensions. I will also discuss the implications of these results for magnetic separators observed in the solar corona.

*12:10 – 12:25* NIC BIAN, *E. Kontar, J. Watters, G. Emslie*
Turbulent reduction of parallel transport in magnetized plasmas and anomalous cooling of coronal loops

We here consider the impact of pitch-angle scattering off turbulent magnetic fluctuations on the parallel transport of electrons in flaring coronal loops. It is shown that the presence of such a scattering mechanism in addition to Coulomb collisional scattering can significantly reduce the parallel thermal and electrical conductivities relative to their Spitzer values. We provide illustrative expressions for the resulting thermoelectric coefficients that relate the thermal flux and electrical current density to the temperature gradient and the applied electric field. We then evaluate the effect of these modified transport coefficients on the flare coronal temperature that can be attained, on the post-impulsive-phase cooling of heated coronal plasma.

## Lunch Break

*12:25 – 14:00* Lunch is provided at “One A The Square”. The restaurant is located at the North-West corner of the Main University Building. Lunch vouchers enclosed in delegates’ conference wallets.

## Session 2: Solar Applications II

*Chairperson:* David Hughes

*14:00 – 14:15* DAVID PONTIN, *G. Hornig, S. Candelaresi*
Braided magnetic fields: equilibria, relaxation, and heating

We examine the dynamics of magnetic flux tubes containing non-trivial field line braiding (or linkage), using mathematical and computational modelling, in the context of testable predictions for the laboratory and their significance for solar coronal heating. We discuss the existence of braided force-free equilibria, and demonstrate that these equilibria must contain current layers whose thickness becomes increasingly small for increasing field complexity for a flux tube line-tied at both ends. In practical terms, the implication is that if one considers a line-tied loop in the solar corona that is driven by photospheric motions, then the eventual onset of reconnection and energy release is inevitable. For a periodic domain braided exact equilibria typically do not exist, while approximate equilibria contain thin current sheets.

*14:15 – 14:30* GUNNAR HORNIG, *A.R. Yeates, A. Russell*
Field Line Helicity

Magnetic helicity is a quantity which measures the pairwise linkage of magnetic flux in a plasma. It is not only a strict invariant under ideal plasma dynamics, but also surprisingly well preserved for magnetic reconnection in a plasmas with a high magnetic Reynolds number. Thus magnetic helicity has been used in many cases to make predictions about the dynamics of plasmas, the most famous being Taylor's relaxation hypothesis for the reversed-field pinch. However, magnetic helicity is only a single number assigned to a magnetic field in a domain. It contains comparatively little information about the topology of the field. Recently the authors showed that one can extract much more information if one considers a helicity per unit flux, or field line helicity. This quantity can in certain cases be used to reconstruct the complete topological information of the field line mapping. We show how to define the field line helicity in a gauge independent way and illustrate how to interpret this quantity with several examples.

*14:30 – 14:45* ANTHONY YEATES, *G. Hornig*
The Global Distribution of Magnetic Helicity in the Sun's Corona

Modern observations are revealing the Sun's large-scale magnetic field to have a complex, non-potential structure. Moreover, it is now widely believed that the loss of equilibrium of twisted magnetic flux ropes is responsible for many (if not all) coronal mass ejections. But predicting where these flux ropes will form, and in particular whether or when they might erupt, remains a challenge for model reconstructions of the coronal magnetic field. In this talk, I will introduce the "field line helicity" as an appropriate and practical diagnostic for identifying twisted structures in coronal models. Since field lines are magnetic sub-domains, this is a more meaningful measure than the density of magnetic helicity at individual points. On the other hand, it provides local information that the globally-integrated magnetic helicity cannot. I will illustrate the power of this diagnostic on my own numerical non-potential evolution model of the global corona.

## Posters and Afternoon Coffee Break

*Chairperson:* David MacTaggart

*14:45 – 15:50* Posters and Coffee Break
(Posters will remain on display in the Maths and Stats Common Room on both days.)

*Poster* ADAM CHILD, *R. Hollerbach, B. Marston, S. Tobias*
Generalised quasi-linear approximation of the HMRI

The magnetorotational instability (MRI) is one of the most important processes in astrophysics, and is the leading candidate for the mechanism by which outward angular momentum transport occurs in magnetised accretion disks. Notably, the presence of an axial magnetic field allows for instability when angular momentum profiles increase with radius, for which purely hydrodynamic flows are stable.
Unfortunately, it is not feasible to run direct numerical simulations (DNS) at the relevant parameters for an astrophysical disk, and so additional approaches are required when investigating the instability.
One such approach is the use of laboratory experiments, whereby an axial magnetic field is applied to liquid metal in the Taylor-Couette geometry. For instability, a magnetic Reynolds number $\mathrm{Rm} \geq O(10)$ is required, which, coupled with the fact that liquid metals typically have magnetic Prandtl number $\mathrm{Pm} \approx O(10^{-6})$, necessitates a Reynolds number $\mathrm{Re} \geq O(10^7)$. This is problematic; under such strong rotation the Taylor-Proudman theorem states that the flow will be dominated by the conditions at the end-plates. As such, this setup has not yet succeeded in producing the standard MRI (SMRI). However, by imposing an additional azimuthal magnetic field, the necessary requirement for instability changes from $\mathrm{Rm} \geq O(10)$ to $\mathrm{Re} \geq O(10^3)$. The resulting helical MRI (HMRI) is continuously connected to the SMRI, has been experimentally reproduced, and is numerically well understood.
Another approach that has recently received much attention is that of direct statistical simulation (DSS), where the low-order statistics are obtained directly from a hierarchy of cumulant equations. It offers a number of advantages over DNS when probing the long time behaviour of astrophysical phenomena. However, it is not currently universally applicable, and there have been a number of examples of inconsistencies with fully nonlinear DNS; current research is focussed on improving the performance of DSS

in such cases.
Motivated by this, we perform DNS on the HMRI under the generalised quasi-linear approximation (GQL), which is essentially equivalent to the cumulant expansions utilised by DSS. The GQL approximation improves upon the standard quasi-linear (QL) approximation by incorporating fully self-consistent interactions of large-scale modes, whilst still being formally linear in the small scales.
Here, we address whether GQL can produce the low-order statistics of axisymmetric HMRI more accurately than the corresponding QL approximation, via diagnostics such as the energy spectra in addition to the first and second cumulants. We find that GQL performs notably better than QL in producing the statistics of the HMRI, even with relatively few large-scale modes. We conclude that DSS based on GQL (GCE2) should be significantly more accurate than that based on QL (CE2).

*Poster*

LARS MEJNERTSEN, *J. Eastwood, J. Chittenden, A. Masters*
Global MHD Simulations of Planetary Magnetospheres

In studying the interaction of the solar wind with planetary magnetospheres, so-called global MHD simulations are a valuable tool. Being able to capture the entire magnetospheric system in an instant in time, they can they can provide a comprehensive overview which is complementary to detailed in-situ measurements. Whilst certain compromises are made to render the calculation feasible, they have been shown to be capable of capturing the general structure of the magnetosphere and global processes. They have also been used to model all the magnetised planets, and aid the interpretation of sparse spacecraft measurements. At Earth such simulations are particularly useful for space weather forecasting, with the ability to take in-situ solar wind observations and determine magnetospheric evolution faster than real time. In this work, we present Gorgon, a 3D MHD code originally developed for modelling laboratory plasmas, which has been adapted to the simulation of planetary magnetospheres, and report on recent progress. Using an Eulerian formation of the resistive MHD equations on a uniform Cartesian grid, it shows good agreement with empirical models and in-situ data. Its use of explicit solvers and efficient parallelization provides it with the ability to provide faster than real time evolution. Previous work has focussed on the implementation of a precessing dipole, and this has been used to simulate Neptune's magnetosphere, focusing on its outer boundaries and the Voyager 2 flyby. These results are reviewed. More recently an ionosphere module has been developed and is being tested. We also describe how the implementation is designed to facilitate coupling to other codes in the future.

*Poster*

TIM WHITBREAD, *A. Yeates, A. Munoz-Jaramillo*
Parameter Optimization for Surface Flux Transport Models

The demand for accurate predictions of solar activity calls for precise calibration of solar cycle models. We present a surface flux transport (SFT) model that takes properties of magnetic active regions, converts them into an appropriate framework and inserts them into the simulation on the day of emergence. A genetic algorithm is used to search for a parameter set for the large-scale flows which produces the best fit between real and model butterfly diagrams for Cycle 23. We also consider a two-dimensional model which inserts specific shapes of active regions into the simulation on the day of emergence and compare it with the simpler one-dimensional case. The entire population from the optimization process can be retrieved and analysed to find ranges of 'acceptable' parameter values. We find that the optimal parameter sets and acceptable ranges are in reasonable agreement with results from literature. Due to the easily-adaptable nature of the models, the optimization process can be repeated for Cycles 21, 22 and the early stages of 24, in order to analyse cycle-to-cycle variation and to find parameter values which accurately reproduce such aspects of the solar cycle as polarity reversal and poleward surges of flux.

*Poster*

GRACE COX, *P. Livermore, J. Mound*
The observational signature of modelled torsional waves and comparison to geomagnetic jerks

Torsional Alfvén waves involve the interaction of zonal fluid flow and the ambient magnetic field in the core. Consequently, they perturb the background magnetic field and induce a secondary magnetic field. Using a steady background magnetic field from observationally constrained field models and azimuthal velocities from torsional wave forward models, we solve an induction equation for the wave-induced secular variation (SV). We construct time series and maps of wave-induced SV and investigate how previously identified propagation characteristics manifest in the magnetic signals, and whether our modelled travelling torsional waves are capable of producing signals that resemble jerks in terms of amplitude and timescale. Fast torsional waves with amplitudes and timescales consistent with a recent study of the 6 yr $\Delta$LOD signal induce very rapid, small (maximum $\sim$2 nT/yr at Earth's surface) SV signals that would likely be difficult to be resolve in observations of Earth's SV. Slow torsional waves with amplitudes and timescales consistent with other studies produce larger SV signals that reach amplitudes of $\sim$20 nT/yr at Earth's surface. We applied a two-part linear regression jerk detection method to the SV induced by slow torsional waves, using the same parameters as used on real SV, which identified several synthetic jerk events. As the local magnetic field morphology dictates which regions are sensitive to zonal core flow, and not all regions are sensitive at the same time, the modelled waves generally produce synthetic jerks that are observed on regional scales and occur in a single SV component. However, high wave amplitudes during reflection from the stress-free CMB induce large-scale SV signals in all components, which results in a global contemporaneous jerk event such as that observed in 1969. In general, the identified events are periodic due to waves passing beneath locations at fixed intervals and the SV signals are smoothly varying. T hese smooth signals are more consistent with the geomagnetic jerks envisaged by Demetrescu and Dobrica than the sharp 'V' shapes that are typically associated with geomagnetic jerks.

*Poster*

ALEXEI BORISSOV, *T. Neukirch, J. Threlfall*

Examining Particle Behaviour in an Analytical Model of Collapsing Magnetic Traps with a Braking Plasma Jet

Collapsing magnetic traps (CMTs) are one proposed mechanism for generating non-thermal particle populations in solar flares. CMTs occur if an initially stretched magnetic field structure relaxes rapidly into a lower-energy configuration, which is believed to happen as a by-product of magnetic reconnection. A similar mechanism for energising particles has also been found to operate in Earth's magnetotail. One particular feature proposed to be of importance for particle acceleration in the magnetotail is that of a braking plasma jet, i.e. a localised region of strong flow encountering stronger magnetic field which causes the jet to slow down and stop. Such a feature has not been included in previously proposed analytical models of CMTs for solar flares. By imposing a background plasma flow we take advantage of the frozen-in magnetic field of ideal MHD to incorporate a braking plasma jet into a well studied CMT model for the first time. We present results of test particle calculations in this new CMT model. We observe and characterise new types of particle behaviour caused by the magnetic structure of the jet braking region, which allows electrons to be trapped both in the braking jet region and the loop legs. We compare and contrast the behaviour of particle orbits for various parameter regimes of the underlying trap by examining particle trajectories, energy gains and the frequency with which different types of particle orbit are found for each parameter regime.

*Poster*

CETIN CAN EVIRGEN, *A. Shukurov, F. Gent, A. Fletcher, P. Bushby*

Statistical geometry of the magnetic field in the multi-phase, turbulent interstellar medium

We discuss the characteristics of magnetic fields in highly compressible, turbulent flows in the interstellar medium (ISM), based on data from numerical MHD simulations [1]. In particular, we are interested in the effect of turbulent flows on the structure of the large-scale galactic magnetic field.
Novel statistical methods, developed using ideas from the field of stereology [2], are used to compare volume samples of gas entropy with samples taken along integral lines [3] of the magnetic field, in order to analyse sensitivity of the magnetic field to the multi-phase structure of the ISM. The large-scale magnetic field shows sensitivity to the multi-phase structure; it preferentially resides in the warm phase. Conversely, the small-scale magnetic field does not show sensitivity to the multi-phase structure.
In addition, we briefly discuss the effect of the galactic magnetic field on the ISM multi-phase structure.

[1] Gent, F. A. Supernova Driven Turbulence in the Interstellar Medium. PhD thesis, Newcastle University, 2012. [2] Baddeley, A. and Jensen, E. Stereology for Statisticians. Taylor and Francis, 2004. [3] Parker, E. Conversations on Electric and Magnetic Fields in the Cosmos. Princeton Series in Astrophysics. Princeton University Press, 2013.

*Poster*

AGNIESKZA HUDOBA

Instabilities in buoyant convective flows

The problem of instabilities in the buoyant convective flows induced by internal heat generation and subject to a high magnetic field is ofparticular importance in the design of liquid metal blankets in thermonuclear fusion reactors. In the present study we investigate linear stability of convective flows with uniformly distributed volumetric heat sources enclosed in an infinite vertical channel and subject to a uniform transverse magnetic field and gravity. The behaviour of the flow when the applied magnetic field increases from zero to high values is examined for different values of parameters. Numerical results show that the instabilities are driven by different mechanisms depending on the Prandtl number, and critically depend on the Hartmann number. At certain values of parameters the marginal stability curve consists of up to four local minima corresponding to different instability modes.

*Poster*

OLIVER BARDSLEY

Rotating-MHD waves from buoyant blobs in the core of the Earth

The magnetic field of the Earth, fostered in its liquid outer core, is driven by a buoyant heat flux from its interior. Effective magnetic field generation can occur if the flow is helical with opposite senses in each hemisphere; it has been suggested [Davidson 2014] that inertial wave packets launched by buoyant anomalies near the equator establish this structure. We study such anomalies, or "blobs", with Gaussian structure and 10km diameter, as a source of helical MHD waves, in three cases: no magnetic field, an axial field (equatorial case), and a horizontal field (off-equatorial case).

## Session 3: Solar Applications III

*Chairperson:* Andrew Soward

*15:55 – 16:10* CHRIS LOWDER, *A.R. Yeates*

Magnetic Flux Rope Identification and Characterization from Observationally-Driven Solar Coronal Models

Flux ropes are frequently defined as bundles of solar magnetic field lines, twisting around a common axis. Formed through a combination of photospheric surface flows and magnetic reconnection, these flux ropes can act to store magnetic stresses as they build in the corona. Beyond a critical quantity of twist, flux rope eruptions can push magnetic field and plasma outward into the heliosphere as a coronal mass ejection (CME). Understanding the formation and eruption of flux ropes is critical in studying and predicting space weather phenomena. Here we present an automated methodology to identify flux ropes within magnetofrictional simulations of the coronal magnetic field, driven by observational data. With this methodology, flux rope volumes are precisely tied down to enable consistent solar-cycle length statistical descriptions of eruption rates, spatial distribution, magnetic orientation, and magnetic flux. Through modification of model parameters and driving input data we arrive at a better understanding of flux rope eruption. For Earth-directed CMEs, potential hints towards associated magnetic orientation, helicity, and flux greatly expand our ability to predict geo-effectiveness.

*16:10 – 16:25* ALAN HOOD, *C. Johnston, I. De Moortel, P. Cargill*

A new approach to chromospheric evaporation due to enhanced coronal heating

We present the results of 1D field-aligned simulations of the coronal plasma response to impulsive heating events. During these events, an increase in the coronal density occurs because the increased coronal temperature leads to an excess downward heat flux that the transition region (TR) is unable to radiate. This creates an enthalpy flux from the TR to the corona. The density increase is often called chromospheric evaporation. Sufficiently high resolution of the TR is essential in numerical simulations in order to obtain the correct coronal density (Bradshaw and Cargill, ApJ, 2013). If the resolution is not adequate, then the downward heat flux jumps over the TR and deposits the heat in the chromosphere, where it is radiated away. Bradshaw and Cargill showed that major errors in simulating the coronal density evolution will occur. Therefore, to compensate for the jumping of the heat flux, when coarse resolutions are used, we propose that the TR should be treated as a discontinuity. We show that, by modelling the TR with an appropriate jump condition, we can remove the influence of poor numerical resolution and obtain the correct coronal density even when using resolutions that are compatible with 3D MHD simulations.

*16:25 – 16:40* DALI KONG, *K. Zhang, G. Schubert*

Using Jupiter's gravitational field to probe the Jovian convective dynamo

Convective motion in the deep metallic hydrogen region of Jupiter is believed to generate its magnetic field, the strongest in the solar system. The amplitude, structure and depth of the convective motion are unknown. A promising way of probing the Jovian convective dynamo is to measure its effect on the external gravitational field, a task to be soon undertaken by the Juno spacecraft. We calculate the gravitational signature of non-axisymmetric convective motion in the Jovian metallic hydrogen region and show that with sufficiently accurate measurements it can reveal the nature of the deep convection.

*16:40 – 16:55* VERONIKA WITZKE, *L. J. Silvers, B. Favier*

Dynamo action in turbulent fully compressible shear flows

Although large-scale magnetic fields are a common feature of many astrophysical objects, such as stars, accretion discs and galaxies, their origin is not entirely understood. In stars, complex gas dynamics in the interior plays a crucial role in magnetic field generation and is also important for mixing processes. Taking the Sun as an example, considerable efforts have recently been directed towards a thin layer with strong shear, the so-called tachocline, and its role in the solar dynamo. To begin the process of obtaining comprehensive knowledge of the motions in stars local three-dimensional direct numerical calculations of unstable shear flows are performed. Focusing on a pure hydrodynamic system the long-time evolution of the resulting turbulent motions in a compressible polytropic fluid is studied. We examine the effect of varying the Prandtl number and thermal diffusivity on the non-linear evolution of an unstable shear flows. In addition, calculations of a low Peclet number instability with large Richardson number are carried out. Finally, we include magnetic fields to study a full magnetohydrodynamical system.

*16:55 – 17:10* JONATHAN HODGSON, *T. Neukirch*
A combined theory for symmetric MHD equilibria with anisotropic pressure and magnetic shear

We present a new approach to the theory of symmetric MHD equilibria with anisotropic pressure and magnetic shear. This approach involves combining two existing formalisms in order to eliminate their individual weaknesses. The resulting formalism gives rise to multi-valued quantities which must be dealt with appropriately. We will give an outline of the theory and then present first results of numerical simulations which make use of the new approach.

## Conference Dinner at Balbir's

*19:00 – 19:30* Drinks reception at Balbir's Indian restaurant in Glasgow's West End.
*19:30 –* Seated for dinner.

**— Friday, 2016-05-13 —**

## Invited Lecture

*Chairperson:* David Fearn

*9:00 – 9:40* PETER A DAVIDSON
How do planetary dynamos work?

We argue that the underlying mechanisms for planetary dynamo action should not depend on the presence of a mantle or on the consequences of viscous stresses, such as Ekman pumping. This lies in stark contrast to many of the numerical geodynamo simulations. If we abandon Ekman pumping as a source of kinetic helicity in planetary cores, we are obliged to find an alternative source which is robust (in the sense that it will necessarily manifest itself in both the terrestrial planets and the gas giants) and also provide the require antisymmetric north-south helicity distribution. We argue that helical waves (either inertial waves or magnetostrophic waves) launched from the equatorial regions may provide the required asymmetric helicity distribution that drives the planetary dynamos we observe.

## Session 4: Geophysical and Planetary Applications

*Chairperson:* Chris Jones

*9:40 – 9:55* KIRILL KUZANYAN, *A.G. Tlatov, V.V. Vasilieva*
New characteristic of solar cyclicity by long term series of filament data

We carry out uniform study of distribution of solar filaments using the data from Meudon Observatory 1919-2003 together with Kislovodsk Mountain Astronomical Station 1979-2014. We scanned and digitized the observed H-alpha synoptic maps, isolating and digitizing filament locations. Data on each filament contain information of the location, length, area, position and other geometric characteristics such as their curvature. We obtained the distributions of the number and the length of filaments with time as well as their latitudinal drift with solar cycle. We also analyzed of the longitudinal distribution, in particular the asymmetry with respect to the northern and southern hemispheres, and other characteristics of filaments.
We also obtained the tilt angles with respect to the equator. On average, western ends of the filament structures are closer to the poles than eastern ones by some 10 degrees in latitude, which we have defined as positive tilts. To the contrary, in the sub-polar regions with latitudes greater than 50 degrees the filament tilt angles are mainly negative. The portion of filaments in the middle-latitude is not large (less than 30%).
The tilt angles vary with the phase of solar cycle attaining their maximum at sunspot maximum activity phase. The highest values for low-latitudinal filaments (below 40 degrees from the equator) have been attained in the middle of 20th century in solar cycles 18-19 at the time of maximum activity. The curvature of filament structures contains properties of twisting and helical properties of large magnetic fields. It can be used as an additional constraint and parameter for development of solar dynamo models.
We hereby propose using statistical properties of solar filaments as an additional coherent measure for manifestation of the solar cycle which covers all latitudes and is systematically calibrated almost for a century long available data series.

*9:55 – 10:10* LONG CHEN, *W. Herreman, K. Li, A. Jackson*
The optimized kinematic dynamo in a sphere

The Earth's magnetic field is generated and sustained by the complex motion of a conducting fluid in the liquid outer core. This phenomenon can be understood in the framework of dynamo theory, which mathematically describes the interaction between the flow and the magnetic field. An outstanding question is which kind of flow can amplify a seed magnetic field. The growth rate of the magnetic field is determined by the competition between magnetic advection and magnetic diffusion. The ratio between the two effects is given by a dimensionless parameter called the magnetic Reynolds number (Rm). A seed magnetic field may grow at a sufficiently high Rm, but the precise threshold for a dynamo driven by a general type of flow is unknown. Given a conducting fluid confined in a domain, what is the lowest Rm to generate a dynamo? We base our Rm on the unit enstrophy norm for the flow, since Rm based on unit kinetic energy is known to have no lower bound from Proctor (2015). We use an optimization method inspired by Willis (2012) to search for the most efficient dynamo solution. This method allows us to maximize the growth rate of the magnetic field over a time window T while imposing other constraints using Lagrange multipliers. We simultaneously look for the optimal steady flow field U and the optimal seed magnetic field B0. We reported the optimization results for flows confined in a cube in Chen et al. (2015). In this talk, I will present the new results in a sphere with electrically insulating boundary condition (BC). The flow satisfies no-slip BC. Compared with previously known dynamo models with the same BC, e.g., Livermore and Jackson (2004), our optimal flow has a lower critical Rm where the magnetic field becomes self-sustaining. We also compare it with other known dynamo models with low critical Rm which may have different flow BCs, e.g., Dudley and James (1989), again our optimal flow exhibits superior efficiency in driving a dynamo, yet still respect the lower bounds found by Backus (1958), Childress (1969) and Proctor (1977). The profile of this flow will be discussed supplemented with visualization.

*10:10 – 10:25* JOSHUA KIRK, *D. Hughes, C. Jones*
Saturn's axisymmetric field: A low Rm nonlinear analysis

Saturn's magnetic field is remarkably axisymmetric. Stevenson (1982) suggested that differential rotation in a stable layer above the dynamo region might explain this strong axisymmetry. Stevenson's model was linear, but we have extended his Cartesian plane layer model to include the additional flows driven by the magnetic field. These include a geostrophic flow that arises due to Taylor's constraint.

*10:25 – 10:40* XIOMARA MARQUEZ, *C. Jones, S. Tobias*
Rotating Magnetic Shallow Water Waves in a Sphere

It has been suggested that there may be a stably stratified layer a few hundred kilometres thick just below the Earth's core mantle boundary. Thin stable layer models can also give insight into the dynamics of the solar tachocline. We have examined the type of waves that occur in such shallow layers in the presence of a magnetic field. We generalise the method of Longuet-Higgins (1966) to solve the differential equations that arise in shallow water MHD (Zaqarashvili et al. 2007). Using an expansion in associated Legendre polynomials, we reduce the differential system to a matrix eigenvalue problem. Taking the original system of five MHD equations, we find the coefficients of the polynomial expansion, which give the eigenvectors, and the eigenvalues which are the frequencies of the modes. We can then reconstruct the spatial form of the eigensolutions for each eigenvalue, giving a complete solution dependent on time, colatitude and longitude. The result of the model shows the presence of Fast and Slow Magnetic Rossby Waves, Magneto Inertial Gravity Waves and Magneto Kelvin modes. The Magnetic Rossby modes could be related to short time secular variation of the Earth's magnetic field.

## Morning Coffee Break

*10:40 – 11:10*

## Session 5: Astrophysical Applications

*Chairperson:* Gunnar Hornig

*11:10 – 11:25* KONSTANTINOS GOURGOULIATOS, *R. Hollerbach, T. Wood*
3-D Simulations of Electron-MHD in magnetar crusts

One of the major unanswered questions related to neutron stars is the origin of the exceptionally high magnetic fields hosted by magnetars, which can reach $10^{15}$ G. Recent observations of magnetars also suggest that the intensity of the magnetic field varies by at least an order of magnitude on their surface, confirming that simple dipolar fields are far from being realistic approximations and leading to additional puzzles regarding the smaller scale structure of the field. I will be presenting 3-D simulations of the evolution of the crustal magnetic field, mediated by electron MHD. These simulations demonstrate that the evolution under e-MHD leads to unstable behaviour creating “magnetic spots” with sizes of a few kilometers. The magnetic fields in these regions are one order of magnitude stronger than the large scale dipole field, accelerating Ohmic dissipation, and providing sufficient heat accounting for magnetars' X-ray luminosities. The strong Maxwell stresses generated can lead to crust yielding and trigger magnetar bursts. Thus, magnetar theory becomes more economical, as localized of strong magnetic field form spontaneously out of a weaker large scale field.

*11:25 – 11:40* MAIRI ELISE MCKAY, *M. Linkmann, A. Berera*

Helical mode interactions and spectral transfer processes in magnetohydrodynamic turbulence

Spectral transfer processes in homogeneous magnetohydrodynamic (MHD) turbulence without a mean field are investigated analytically by decomposing the velocity and magnetic fields in Fourier space into positive and negative helical modes. In 1992, Waleffe (Phys. Fluids A, 4:350 (1992)) used the helical decomposition to construct a system of equations which describes the evolution of a triad of helical modes in homogenous, isotropic hydrodynamic turbulence. From this, he established whether or not a given triad interaction would contribute to a forward or reverse transfer of energy. When a magnetic field is coupled to the velocity field, the dynamics become even more complex as any triad interaction involves six, rather than three, modes. Inspired by Waleffe's analysis, we determine steady solutions of the dynamical system which governs the evolution of the helical modes and carry out a stability analysis of these solutions, the interpretation being that unstable solutions lead to energy transfer between the interacting modes. We find that the possible energy and helicity transfers depend not only on the combination of positive and negative helical modes in a triad interaction, but in certain cases also on the magnitude and cross-helicity of the magnetic and velocity fields. As expected from the inverse cascade of magnetic helicity in 3D MHD turbulence, mode interactions with like helicities lead to the transfer of energy and magnetic helicity to smaller wavenumbers. However, some interactions of modes with unlike helicities also contribute to an inverse energy transfer. As such, an inverse energy cascade for non-helical magnetic fields is shown to be possible. Furthermore, we find that high values of the cross-helicity may have an asymmetric effect on forward and reverse transfer of energy, where forward transfer is more quenched in regions of high cross-helicity than reverse transfer. This agrees with recent observations of solar wind turbulence. For specific helical interactions the relation to dynamo action is established. The analysis provides new theoretical insights into physical processes where inverse cascade and dynamo action are involved, such as the evolution of cosmological and astrophysical magnetic fields and laboratory plasmas.

*11:40 – 11:55* ANGELA BUSSE *J. Pratt, W.-C. Müller*

Statistical properties of tracer trajectories in homogeneous MHD turbulence

Turbulent flow occurs in many astrophysical systems, such as convection in stars, stellar winds and the interstellar medium. Magnetohydrodynamic turbulence differs significantly from standard hydrodynamic turbulence. For example, in hydrodynamic turbulence small-scale vorticity tends to be organised in the form of vortex filaments, whereas vortex sheets are observed in the MHD case. The structure of MHD turbulence has mainly been studied from the Eulerian perspective. In this contribution, the structure of MHD turbulence is investigated from the Lagrangian viewpoint based on the trajectories of passive tracer particles. Results for the statistical properties of the trajectories will be presented, including acceleration and curvature statistics, and examples of characteristic tracer trajectories will be discussed.

*11:55 – 12:10* AMIT SETA, *P. Bushby, A. Shukurov, T. Wood*

Cosmic Ray Propagation in Intermittent Magnetic Fields

Cosmic rays, highly energetic charged particles, are an important component of the interstellar medium (ISM) in galaxies as they have the same energy as thermal gas, turbulence and magnetic fields. The cosmic rays diffuse through the ISM both due to the the random walk of magnetic lines and scattering by self-generated Alfven waves. The propagation of cosmic rays is usually analyzed in synthetic turbulence and we aim to study the propagation of cosmic rays in random magnetic field generated by the fluctuation dynamo. There are two competing effects: the trapping of particles within the structures and Levy flights between such structures. The structure of magnetic field which cosmic rays encounters depend on the magnetic Reynolds number and the particle's Larmor radius or energy. Thus, there are different regimes of cosmic ray diffusion depending on the energy and we find that the intermittency of the dynamo generated magnetic field strongly affects the energy dependence of the cosmic ray diffusivity.

*12:10 – 12:25* JAMES HOLLINS, *A. Fletcher, G. Sarson, A. Shukurov, F. Gent*

Space- and time-correlations in the supernova driven interstellar medium

We apply correlation analysis, initially assuming horizontally isotropic turbulence, to determine the correlation lengths of turbulent magnetic, density and velocity fields in numerical simulations of the Interstellar Medium (ISM). The simulations, based on the Pencil Code (http://pencil-code.nordita.org/), solve the full MHD equations in a shearing, Cartesian box, driven by supernova explosions. From our analysis of the turbulent velocity, we estimate the Taylor microscale of our simulations. We compute the correlation time of our simulations and compare this to estimates of the eddy turnover time and time between supernova shocks.

## Lunch Break

*12:10 – 14:00* Lunch is provided at "One A The Square". The restaurant is located at the North-West corner of the Main University Building. Lunch vouchers enclosed in delegates' conference wallets.

## Session 6: Models and Methods

*Chairperson:* Tony Arber

*14:00 – 14:15* LAURA CURRIE, *Matthew Browning*

Dissipation in convective flows

Hewitt et al. (1975) showed that the importance of dissipative heating in a convecting fluid (by processes such as viscous or ohmic heating) depends on the ratio of the depth of the convecting region (d) to the temperature scale height ($H_T$). They showed that, for liquids under certain conditions, the ratio of the global dissipative heating rate to the convected heat flux is approximately equal to $cd/H_T$, where c is a constant independent of the Rayleigh number; they confirmed this result using numerical simulations of a convecting layer under the Boussinesq approximation (which is valid only if $d/H_T$ is small). In many astrophysical contexts, the Boussinesq approximation is not valid and convection occurs over many scale heights. We carry out numerical experiments to investigate the importance of dissipation as the stratification of a convecting layer is increased, making use of the anelastic approximation. We consider the influence of dissipative heating on both local an global scales and test if the ratio of the dissipative heating rate to the convected heat flux remains proportional to $d/H_T$ in regimes different to those studied by Hewitt et al. The results potentially have implications for the modelling of stellar interiors, where modern standard evolutionary codes do not currently allow for dissipative heating.

*14:15 – 14:30* VALERIA SHUMAYLOVA, *M.R.E. Proctor*

Kinematic dynamo action: Transition from large- to small-scale

Magnetic fields on the Sun exist on a vast range of spatial and temporal scales that coexist in the physical processes. They can be categorised as large-scale and small-scale fields. The Sun's large-scale magnetic field exhibits coherence in space and time on much larger scales than the turbulent convection that ultimately powers the dynamo. Moffatt (1978) and Krause (1980) introduced the framework of mean-field theory to describe the origin and self-sustainment of a large-scale magnetic field in astrophysical objects. The theory outlines how small-scale turbulent motions produce a coherent global field through the interaction with small-scale magnetic fields in the limit of high magnetic diffusivity.

We investigate the spatial scale selection for coherent structures of magnetic fields due to the dynamo action in the presence of a velocity field that has a single spatial scale (classic ABC flow) and a two-scale velocity field with a long modulation. Mean-field theory predicts long wavelength modes at the onset of dynamo action, whereas small scales are more energetic at larger $R_m$. The transition from large- to small-scale dynamo is of interest.

We test this idea numerically by considering a cuboid that is extended in one direction and includes multiple copies of the periodic cell of the flow, to examine whether the magnetic field can grow on scales longer than that of the flow as the magnetic Reynolds number is increased.

By using spectral filtering we demonstrate that the scales responsible for dynamo action are consistent with those predicted by the asymptotic theory in the range it is expected to apply to. The simulations showed that the critical $R_m$ is related to the longest scales in a box. The transition from large scales to small scales at different $R_m$ for the two flows, so the mean-field approximation is valid for a varying range of magnetic diffusivities yet still limited to the low $R_m$ regime.

*14:30 – 14:45* WAYNE ARTER

Simple Model for Reconnection

The linear fields model of ideal compressible MHD, introduced in Dungey's "Cosmic Electrodynamics" has been examined in a more general context including 3-D effects and dissipation. Aspects relevant to the meeting will be discussed, specifically transient behaviour and the role of resistivity.

*14:45 – 15:00* FIONA WILSON, *T. Neukirch*

Three-Dimensional Analytical Magnetohydrostatic Equilibria of Rigidly Rotating Magnetospheres in Cylindrical Geometry

We present a discussion of three-dimensional magnetohydrostatic equilibria, which are relevant to (for example) rigidly rotating planetary magnetospheres. A certain class of such equilibria can be found using a method developed by Low (e.g. ApJ, 293, 31-43, 1985). For the case with centrifugal force only, and in cylindrical geometry, such equilibria have been found by Neukirch (Geophysical and Astrophysical Fluid Dynamics, 103, 535-547, 2009) through the use of a transformation method. We discuss the use of this method and present further solutions, which extend the results of the 2009 paper. We also discuss issues associated with the extension of the transformation method to spherical geometry.

*15:00 – 15:15* MAT HUNT, *J. Sivaloganathan*

A New Formulation of Incompressible Magnetohydrodynamics and its Application to Jets

We present a new formulation of incompressible magnetohydrodynamics based on the idea of deformation gradients put forward by A. Majda et al. in [1] giving a direct relationship between the vorticity of the fluid and the current density of the magnetic field. We then specialise to a homogeneous solutions to examine some properties of the equations vis jetting phenomena.
References: Majda, A. and Bertozzi, A, Vorticity and incompressible flow, CUP

*15:15 – 15:30* YUE-KIN TSANG, *J. Mason*

Effects of a guided-field on particle diffusion in magnetohydrodynamic turbulence

We consider three-dimensional incompressible magnetohydrodynamic turbulence in the presence of a background magnetic field. We examine the Lagrangian properties of the system by numerically tracking a large number of passive massless particles. We find that the mean-squared-displacement grows linearly in time indicating diffusive behaviour. However, as the strength of the guided-field increases, the diffusion becomes anisotropic with larger diffusivity in the field-parallel direction. Associated with such transition are changes in the behaviour of the energy spectrum and the Lagrangian velocity correlation function. In particular, the Lagrangian velocity decorrelation time exhibits a power-law scaling with the root-mean square velocity and the scaling exponent shifts from -1 to -2 as anisotropy develops in the system.

## End of Meeting Coffee Break

*15:30 – 16:00*

**— Withdrawn Contributions—**

*Withdrawn talk* MARION WEINZIERL, *A.R. Yeates, D.H. Mackay, C.J. Henney, C.N. Arge*

A New Technique for the Photospheric Driving of Non-Potential Solar Coronal Magnetic Field Simulations

A new technique for driving global non-potential simulations of the Sun's coronal magnetic field solely from sequences of radial magnetic maps of the solar photosphere is presented. A primary challenge to driving such global simulations is that the required horizontal electric field cannot be uniquely determined from such maps. We show that an "inductive" electric field solution similar to that used by previous authors successfully reproduces specific features of the coronal field evolution in both single and multiple bipole simulations. For these cases the true solution is known because the electric field was generated from a surface flux transport model. The match for these cases is further improved by including the non-inductive electric field contribution from surface differential rotation. Then, using this reconstruction method for the electric field, we show that a coronal non-potential simulation can be successfully driven from a sequence of ADAPT maps of the photospheric radial field, without including additional physical observations which are not routinely available.

*Withdrawn talk* MOULOUD KESSAR, *F. Plunian, R. Stepanov, G. Balarac*

Non-Kolmogorov cascade of helicity driven turbulence

Homogeneous and isotropic turbulence was first formalized by Kolmogorov (1941), through dimensional analysis. He managed to show that the spectral density of kinetic energy, $E(k)$, was following a $k^{-5/3}$ law. This behaviour is known as Kolmogorov's cascade. For many geophysical and astrophysical flow, kinetic helicity plays an important role. For instance, Parker (1955) showed that for conductive fluids such as Sun, kinetic helicity could contribute to amplify the magnetic field. Brissaud *et al* (1973) tried to show that kinetic helicity could have an influence on the spectral density of kinetic energy. Through dimensional analysis they suggested the existence of a cascade for which the kinetic energy spectra would follow a $k^{-7/3}$ law. We will confirm thanks to Direct Numerical Simulations (DNS) the existence of such an asymptotic limit in $k^{-7/3}$. We will also use helical decomposition to perform a deep analysis of the physics encountered within such flows.

## — List of Participants —

1. Peter Davidson, University of Cambridge
2. Philippa Browning, University of Manchester
3. Marion Weinzierl, Durham University
4. Kumiko Hori, University of Leeds
5. James Threlfall, University of St Andrews
6. Anthony Yeates, Durham University
7. Valeria Shumaylova, University of Cambridge
8. Tony Arber, University of Warwick
9. Yue-Kin Tsang, University of Exeter
10. Laura Currie, University of Exeter
11. Tim Whitbread, Durham University
12. Xiomara Márquez, University of Leeds
13. Daniel Miller, University of Exeter
14. Jamie Quinn, University of Glasgow
15. Adam Child, University of Leeds
16. David Hughes, University of Leeds
17. Joshua Kirk, University of Leeds
18. Keke Zhang, University of Exeter
19. Gert Botha, Northumbria University
20. Lars Mejnertsen, Imperial College London
21. Grace Cox, University of Liverpool
22. Chris Jones, University of Leeds
23. Dali Kong, University of Exeter
24. Mouloud Kessar, University of Leeds
25. Robert Teed, University of Cambridge
26. Joanne Mason, University of Exeter
27. Long Chen, ETH Zurich
28. Daniela Weston, University of Leeds
29. Alexei Borissov, University of St Andrews
30. Ben Snow, Northumbria University
31. Andrew Hillier, University of Cambridge
32. Wayne Arter, Culham Centre for Fusion Energy
33. Hope Thackray, University of Sheffield
34. Mairi McKay, University of Edinburgh
35. Agnieszka Hudoba, Coventry University
36. Steven Tobias, University of Leeds
37. Chris Lowder, Durham University
38. Amit Seta, Newcastle University
39. Cetin Evirgen, Newcastle University
40. Nicolas Bian, University of Glasgow
41. Fiona Wilson, University of St Andrews
42. Jonathan Hodgson, University of St Andrews
43. Veronika Witzke, City University London
44. Angela Busse, University of Glasgow
45. Oliver Bardsley, University of Cambridge
46. Karen Meyer, Abertay University
47. James Hollins, Newcastle University
48. Abrar Ali, City University London
49. David Pontin, University of Dundee
50. Konstantinos Gourgouliatos, University of Leeds
51. Richard Ho, University of Edinburgh
52. Andrew Michael Soward, Newcastle University
53. Alan Hood, University of St Andrews
54. Radostin Simitev, University of Glasgow
55. David MacTaggart, University of Glasgow
56. David Fearn, University of Glasgow
57. Nicholas Hill, University of Glasgow
58. Luigi Vergori, University of Glasgow
59. Steven Roper, University of Glasgow
60. Peter Stewart, University of Glasgow
61. Kirill Kuzanyan, Russian Academy of Sciences
62. Mat Hunt, University of Bath
63. Gunnar Hornig, University of Dundee

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## — Website —

http://www.gla.ac.uk/schools/mathematicsstatistics/events/conferences/ukmhd2016