Invited Talk.

Jane Pratt  
University of Exeter  
Magnetic islands under the influence of heating and current  
Magnetic reconnection is a fundamental process in plasmas, complementary to the dynamo. In astrophysical contexts, magnetic reconnection can be observed on large scales. In a fusion plasma, the goal is not only to observe, but to manipulate the reconnection process and the magnetic islands that result. I will present a broad review of magnetic reconnection. In the context of my own research, I present the a numerical study of the dynamics of magnetic islands that are formed by magnetic reconnection. I explore how heating and current influence a magnetic island’s growth, and discuss implications for suppression and prevention of a tearing mode in a tokamak fusion reactor.

Session 1 - Geophysical and Planetary.

Oliver Bardsley, Peter Davidson  
University of Cambridge  
Rapidly-rotating MHD waves from localised sources in planetary cores  
We consider radiation from a localised source in a rapidly-rotating high-Rm system, thought to be reminiscent of the small-scale dynamics in a planetary core. Hybrid magnetic-Coriolis waves, oscillations which arise through the competition of inertial, Lorentz, and Coriolis forces, disperse energy from the source. In a planetary core, for which the rotation dominates the background magnetic field, the literature suggests that the waves observed should comprise two well-separated roots: fast inertial waves (weakly modified by the magnetic field) and slow magnetostrophic waves (possessing no inertia). However, we show through a model problem with an imposed background field that both of these wave types are of secondary importance, and that a third type - the unstudied ‘inertial-Alfvén wave’ - in fact dominates. We explain the unexpected prevalence of these waves through comparison with the hydrodynamic case, and discuss consequences for the generation of columnar structures within planetary cores.

Xing Wei  
Shanghai Jiao Tong University  
Precession dynamo and dynamical tides  
I will report my recent results of two projects. The first one is about the planetary magnetic fields driven by precession. The interaction of convection and precession is numerically studied and it is found that the two driving mechanisms destabilise each other such that the presence of precession facilitates the onset of dynamo action. The second one is about nonlinear and magnetic effects on dynamical tides. The effect of nonlinear inertial force on dynamical tides is numerically studied and it is found that the nonlinear effect tends to suppress the tidal response and dissipation near the resonant frequency. The effect of magnetic fields on dynamical tides is analytically studied under the WKB approximation and it is found that even week fields will
have a significant contribution to tidal dissipation.

**Peter Davidson**  
University of Cambridge  
_Dynamos driven by helical waves: scaling laws for numerical dynamos and for the planets_  
We derive scaling relationships for planetary dynamos based on a balance between energy production and Joule dissipation, and between the curl of the buoyancy and Coriolis forces. These scaling relationships are deduced for the particular case of dynamos driven by helical waves, but are shown to have a much broader applicability. They are consistent with the evidence of the numerical dynamos, yielding predictions consistent with published empirical scaling laws and also with the observed transition from dipolar to multipolar dynamos. A direct comparison with the observational evidence for the planets is hampered by the fact that we do not know what sets the smallest scale of the motion in the planets. Nevertheless, we use our scaling relationships to show that the traditional assumption that the Elsasser number is of order unity is inconsistent with the observation that the gas-giant dynamos are dipolar dynamos, as is the more recent suggestion that the strength of the dipole is independent of rotation rate and controlled by the buoyancy flux alone. On the other hand, we show that the observational data is consistent with the hypothesis that a dipolar dynamo saturates at the lowest permissible magnetic energy compatible with a given buoyancy flux.

**Avishek Ranjan, Peter Davidson, Ulrich Christensen, Johannes Wicht**  
University of Cambridge  
_Internally-driven inertial waves in geodynamo simulations_  
Inertial waves are oscillations in a rotating fluid, such as the Earth’s core, which result from the restoring action of the Coriolis force and the conservation of angular momentum. Columnar flow structures vertically spanning much of the core are a robust feature of most geodynamo simulations with rapid rotation. These are often interpreted in terms of boundary-driven columnar eigenmodes, steady solutions of a boundary-value problem (BVP) in a rotating, internally-heated spherical shell. However, the turbulent convection dynamics in the core is likely to be unsteady and the assumptions in the BVP are therefore tenuous. This necessitates an alternate mechanism to explain the columnar structure formation.

We report internally-driven inertial waves in a geodynamo simulation at high Rayleigh number \( \left( \frac{Ra}{Ra_{\text{critical}}}=42.4 \right) \) and low Ekman number \( E=3\times10^{-5} \). We use the MagIC code which solves the Navier-Stokes equations, coupled with the induction and temperature equations, in the Boussinesq approximation for a rotating, electrically-conducting fluid in spherical shell representative of Earth’s geometry. Using cylindrical co-ordinates, we study the time-series of (a) temperature perturbations and (b) a time-derivative of vertical velocity \( \frac{dw}{dt} \). In these results, we find internally-driven inertial waves triggered by buoyant anomalies near the equator. These are low-frequency inertial waves which propagate vertically upwards (downwards) north (south) of the equator on a fast time-scale. We find that the slopes observed in the time-series of \( \frac{dw}{dt} \) match closely with those expected from the group speed of low-frequency inertial waves. Moreover, the spectrum of \( \frac{dw}{dt} \) lies in the inertial wave frequency range. We speculate that the columnar flow in the rotation-dominated core, an important ingredient for the maintenance of the dipolar magnetic field, is driven and maintained on a fast-time scale by low-frequency, internally-driven inertial waves.

**Chen Long**  
ETH Zurich  
_The ultimate lower bounds on dynamos in a sphere_  
In dynamo theory, the growth of a magnetic field in a given system is related to the magnetic Reynolds number (Rm). Given a conducting domain with a fixed general class of flows, we want to find the ultimate lower bound on Rm below which no dynamo solutions exist. We focus on the instantaneous growth of a magnetic field induced by steady flow fields. Any unsteady flow field
at a given instance can be approximated by steady flow fields in this way. We apply a variational method based on Willis (2012) to search for the most unstable eigenmodes of both a steady flow field and a seed magnetic field over a very short time window. In this talk, I will present the ultimate lower bounds and the corresponding optimal fields for a variety of boundary conditions and symmetry classes in a sphere.

Session 2 - Solar 1.

Valeria Shumaylova
University of Cambridge
Coarsening magnetic instability in domains of large aspect ratio: ABC and modulated flows

The Sun’s magnetic field exhibits coherence in space and time on much larger scales than the turbulent convection that ultimately powers the dynamo. In this work, we look for numerical evidence of a large-scale magnetic field as the magnetic Reynolds number, $R_m$, is increased for fixed Reynolds number, $R_e$, in both the laminar and turbulent regimes for the forced flows considered. The investigation is based on the incompressible MHD simulations in elongated periodic boxes. The forcing functions considered are given by the viscous body forcing in the form of the standard ABC flow with wavenumber $k^u = 1$ (small-scale) and a modulated ABC flow with wavenumbers $k^u = m, 1, 1 \pm m$, where $m$ is the wavenumber corresponding to the long-wavelength perturbation on the scale of the box. Our results show an inverse cascade of magnetic energy. We characterise the observed coarsening dynamics associated with the classic ABC and modulated flows under the mean-field theory framework. Our analytical coarsening law stands in good qualitative agreement with large-scale numerical simulations.

Thomas Howson
University of St Andrews
The effects of dissipation on the development of the Kelvin-Helmholtz instability in transversely oscillating coronal loops

Many observations of transversely oscillating coronal loops have been reported in recent years. Typically these waves have a damping rate far in excess of that predicted by the expected levels of dissipation in the corona. This enhanced damping is thought to be caused by the process of resonant absorption through which energy is transferred to azimuthal Alfvénic waves. These waves are associated with the small length scales required for efficient energy dissipation. In addition, the large velocity shear associated with the localised azimuthal waves may trigger the Kelvin-Helmholtz instability. We investigate the effects of dissipation on the growth rate of the instability and comment on the potential consequences for coronal heating.

Alexei Borissov
University of St Andrews
Anomalous resistivity in MHD simulations of magnetic reconnection: Effects on particle scattering

In order to achieve the fast time scales of energy release in solar flares an anomalous resistivity, which is much higher than the Spitzer resistivity, is often used in MHD simulations of reconnection in the corona. The origin of Spitzer resistivity is due to Coulomb scattering, which becomes negligible at the high energies associated with accelerated particles. As a result, simulations of particle acceleration in reconnection events are often performed in the absence of any interaction between the accelerated particles and the background plasma. This need not be the case for scattering caused by anomalous resistivity. We present results of particle orbit calculations in background fields given by multiple MHD simulations of 2D reconnection. The effects of anomalous resistivity are reflected on the particle dynamics through several different models of pitch angle scattering, and are clearly seen in differences in the energy spectra of the accelerated test...
particle population. In addition to changes in the final energy spectra, changes to the distribution of final positions of the test particle orbits are also observed.

Tim Whitbread
Durham University

*Parameter optimization for surface flux transport models*

Accurate prediction of solar activity calls for precise calibration of solar cycle models. Consequently we aim to find optimal parameters for models which describe the physical processes on the solar surface. We use a genetic algorithm to optimize surface flux transport models using NSO magnetogram data for Cycle 23. This is applied to two models with distinct dimensionality and assimilation methods. The genetic algorithm searches for parameter sets that produce the best fit between observed and simulated butterfly diagrams, weighted by a latitude-dependent error structure which reflects uncertainty in observations. Due to the easily-adaptable nature of the 2D model, the optimization process is repeated for other cycles in order to analyse cycle-to-cycle variation of the optimal solution. We find that the ranges and optimal solutions for the various regimes are in reasonable agreement with results from the literature, both theoretical and observational. Differences between models appear to be important in deciding values for the diffusive and decay terms. In like fashion, differences in the behaviours of different solar cycles lead to contrasts in parameters defining the meridional flow and initial field strength.

Roger Scott, David Pontin, Gunnar Hornig
University of Dundee

*Application of the transport integral method to global estimates of the magnetic squashing factor*

Unlike the fast solar wind, which is thought to emanate from within coronal holes, the source and nature of the slow solar wind is not yet clear. One possibility is that an ongoing interchange reconnection process allows for the continuous exchange of material between open and closed flux domains, which might explain both the composition and variability of the slow solar wind. In order to characterize this effect, we have undertaken a survey of quasi-separatrix layers (QSLs) in global field models, in order to identify likely candidate geometries for simulations of interchange reconnection. The size and geometry of the numerical domain in global models, combined with the need for adaptive refinement, make the QSL Squasher code (Tassev & Savcheva, 2016) an ideal platform for this study. In addition to various optimization techniques in the code, one of the key features of QSL Squasher is its novel approach to characterizing the mapping - rather than constructing the mapping explicitly through field line tracing, the code tracks the separation between ‘adjacent’ field lines, and then integrates these to get the deformation of the mapping. But while this technique is fast, its derivation is predicated on a perturbative description of the magnetic field, and so the accuracy of the method is not, as yet, well understood. Here, we present an alternate formulation, which makes rigorous the connection between the deformation of the field and the transport of vectors along individual field lines, thereby validating the method of Tassev & Savcheva (2016) and also generalizing it for mappings between surfaces of arbitrary orientation. We then consider a worked example, which demonstrates the exact analytical solution in the familiar case of a linear magnetic null, and we offer a comparison to numerical results obtained from the QSL Squasher code. We then go on to apply the method to a global field model, identifying a variety of topologically interesting structures that are connected to the heliospheric current sheet, making them ideal candidates for the study of interchange reconnection as a potential driver of the slow solar wind.

Juie Shetye
Armagh Observatory

*Observations of high-frequency waves in the spicules - A solution to the coronal heating paradigm*

We present a statistical study of spectral images, taken from the CRISP instrument at the
Swedish 1-m Solar Telescope in H-alpha 656.28 nm of high-speed spicules with Doppler velocities in the range of -41 km/s to +41 km/s. Remarkably, many of these spicules display apparent velocities above 500 km/s, very short lifetimes of up to 20 s combined with width or thickness of 100 km and lengths of around 3500 km. We observed transverse motion associated with these structures which in some cases could be related to high-frequency kink-waves, high-frequency torsional Alfvén waves or high-frequency helical kink waves. We also observe examples of multiple-MHD modes present when these features interact. Also, we show simulations that represent evolution and propagation of these waves from the photosphere to the lower corona. These waves carry enough mass and energy to contribute to towards the energy budget of the corona.

Posters.

RYAN EDGAR, Stephane Régnier
Northumbria University
The topology of X-class during the SDO era
Since the launch of the Solar Dynamics Observatory (SDO) in 2010, the activity of the Sun has produced a few tens of X-class flares. Using a potential field model, we use the high-cadence high-resolution SDO/AIA and SDO/HMI to correlate the site of the flaring activity and the location of magnetic null points. There is no 1:1 correlation between magnetic null points and flare sites. However, we determined that the flare sites are associated to a null point in the case of a reverse-Y magnetic configuration in which the polarity inversion lines are in the East-West direction. In some cases where there is no association between flare sites and null points, we have been able to discriminate the mechanism of eruption. For instance, one example shows a clear filament instability followed by a flare below the filament characteristic of a tether-cutting mechanism, while another active region shows the expansion of the large-scale loops before the flare consistent with the breakout model. In other cases, the mechanism of eruption is still undetermined.

LEWIS IRELAND
University of Exeter
Investigating the effects of rotation and magnetism on stellar radii in 1D stellar structure models
Some low-mass stars (LMS) appear to have larger radii than predicted by standard one-dimensional stellar models. The origins of these inflated radii are unknown, but several authors suggest that inefficient convective heat transport is ultimately to blame. We aim in particular to understand whether the unexpectedly large radii measured in some LMS can be explained by a decrease in convective efficiency, due to rotation or magnetism. Standard one-dimensional structure models do not explicitly include the effects of rotation and magnetism on convection, but these may be modelled simply by varying the mixing-length parameter $\alpha_{\text{MLT}}$.

Using the MESA stellar evolution code, we modify the standard MLT formulation to mimic rotational and magnetic effects on the stellar structure, using formulations suggested by Stevenson (1979) and MacDonald & Mullan (2012) respectively. We find that for these models, rapid rotation has a negligible effect on the stellar structure, essentially because the overall radius is affected most by layers near the surface, where convection tends to be rapid and thus largely uninfluenced by rotation. Magnetic fields, if they indeed influence the convective transport in the manner described by MacDonald & Mullan (2012), could lead to much more noticeable inflation of the radius.

We show that these effects on the stellar structure can be reproduced using a depth-dependent $\alpha_{\text{MLT}}$: that is, a non-magnetic non-rotating model can be constructed that almost reproduces the solution to these ‘magnetic’ models. We also demonstrate how the ratio of stellar radii between fully-convective LMS models can be determined from a change in the adiabatic specific entropy, and how this scales with changes in $\alpha_{\text{MLT}}$ for standard one-dimensional structure models with
radius inflation $\leq 10\%$.

**Anthony Yeates**  
Durham University  
*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. Recently, we have identified the field line helicity is 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.

**Hope Thackray**  
University of Sheffield  
*Fast MHD waves in cylindrical geometry*

The three-dimensional cylindrical waveguide for modelling coronal oscillations, proposed by Hindman and Jain (2015), manifests the trapping of MHD fast waves. More specifically, the waveguide consisting of two shells at an interface, where the density above the interface is greater than in the cavity below, shows elliptically polarised oscillations, similar to the observations. Here, we introduce a small shell of inhomogeneity in the two-shell model, to study the changes in the reflective properties of the cavity. Using semi-analytical solutions of the derived linear MHD governing equation, we show that the resultant eigenfunctions possess both propagating and evanescent modes, with radial and axial motion. We find that, depending on the properties of the inhomogeneous shell, there could be suppression of some radial modes.

**Chris Prior**  
Durham University  
*Coronal dynamics of braided flux ropes*

A number of simulations of the dynamics evolution of braided magnetic flux ropes are presented. In one case we embed flux ropes of realistic morphology in dipole and quadruple background fields. Both internally twisted and braided fields are placed in identical environment and their behaviour compared. The braided field’s global morphology is stable by comparison to the eruptive twisted ropes, suggesting complex topology can stabilise current carrying elements in the coronal region. In addition a study tracking the emergence of braided flux ropes through the transition region is presented. We find braided flux ropes could appear as weakly twisted fields using standard observational signatures, though their field structure would be greatly different.

**Gert Botha, Daniel Johnson, Micah Weberg, Shaun Bloomfield**  
Northumbria University  
*Waves and turbulence in the solar wind during solar cycle 23-24 minimum*

Waves and turbulence in the solar wind are studied during the solar minimum between cycles 23 and 24. From the ACE and WIND satellites at L1 we obtain observations of the magnetic field, density, velocity and particle abundances, on which we perform a spectral analysis (Lomb-Scargle and wavelet). These spectral results are used to characterize the solar wind, which is compared with Carrington maps using SOHO/EIT 193 Å in order to identify salient features. The sound and Alfvén speeds, i.e. the plasma beta, are calculated and the types of MHD waves in the turbulence are identified. We obtain distinct signatures for the slow and fast solar wind components and give an analysis of the wave and turbulence properties in each case.
Standing waves in plume and fan-loop

We report standing oscillations in coronal loops and plumes as seen from AIA/SDO. We find that oscillations are triggered by the incoming shock wave generated from nearby flare. The incoming shock hit and compress the plasma inside the coronal loop and the plume, thereby triggering the standing slow wave. We also find that these oscillations are damped. We performed the DEM analysis and estimated the temperature and density inside these structures. This phenomena is ubiquitous and if initial conditions are right then these structures can support standing slow waves. Some initial observational results will be presented.

WKB solution for fast magnetoacoustic wave behaviour around a 3D null point

We study the propagation of a fast magnetoacoustic wave in a 3D magnetic field created from a uniform magnetic field and a dipole. The magnetic topology contains a three-dimensional null point. We aim to contribute to the overall understanding of MHD wave propagation within inhomogeneous media, specifically around 3D nulls. We investigate the linearised, 3D MHD equations under the assumptions of ideal and cold plasma. We utilise the WKB approximation and Charpit’s method during our investigation.

Heating profiles in Braginskii MHD

In a strongly magnetized plasma, such as most of the solar corona, the plasma viscosity is anisotropic with the magnetic field giving the preferred direction of momentum transport. However, at null points, where the magnetic field is zero, there is no longer a preferred direction and viscosity must revert to the standard isotropic form. This poster describes Braginskii MHD, which is single-fluid MHD with an anisotropic viscosity tensor that behaves as described above. We demonstrate that the viscous heating profiles in plasmas can be significantly different if anisotropic viscosity is used rather than just isotropic viscosity (as is common in most coronal MHD models).

A study of a tornado-like quiescent solar prominence and its eruption

A number of MHD instabilities are thought to be important in the eruption of solar prominences / filaments. Instabilities in prominence cavities can be categorized as flow-driven (plasma dominated) and field-driven (magnetic field dominated). Despite significant progress in observational analysis of prominence plasma very little is known about its magnetic nature. Here we use height-time plots to track the leading edge of the 27th Feb 2013 prominence eruption, via radial slits, using coordinated SDO/AIA and NoRH observations. From the derivatives of the height-time properties we deduce kinematic properties such as velocity and acceleration profiles. The kinematics are analysed to investigate important new correlations between the kink and torus instabilities.

Modelling explosive events in the solar corona

Energetic events in the solar corona accelerate charged particles, resulting in phenomena such as coronal mass ejections (CMEs) and hard X-ray flare footpoints. Several acceleration mechanisms have been proposed which need to be tested with simulations. We will write a high order kinetic code that uses magnetic and electric fields interpolated from an MHD simulation. The code
will be tested by attempting to replicate the motion of charged particles in a flat current sheet solved analytically by Speiser (1965). Our main goal will be to use this code to simulate particle acceleration near 3D magnetic reconnection sites in the corona.

Session 3 - Solar 2.

**Kirill Kuzanyan, Nathan Kleeorin, Igor Rogachevskii, Andrei Tlatov, Dmitry Sokoloff**

IZMIRAN, Russian Academy of Sciences

*Theoretical estimates of tilt, twist and current helicity in solar active regions versus their observational manifestations*

Tilt of sunspots is believed to be an important driver of the solar dynamo mechanism. Its observational studies have a long history. Current helicity and twist of magnetic fields in solar active regions are proxies of magnetic helicity which is an inviscid invariant in MHD convection motions. These quantities are measurable in the Sun already for several cycles, and used in mean field dynamo models for describe self-consistent evolution of helicity and magnetic fields.

In this work, using a basic model for convection on super-granulation scales below the solar photosphere we estimate the amount of tilt and twist (current helicity) of bipolar active regions on their rising phase due to Coriolis force, and compare these results with intrinsic twist (and helicity) of magnetic field from mean-field dynamo models. We also compare the results with available observations of tilt and current helicity from statistical studies of magnetograms of the solar photosphere.

The results show that the both amounts of twist produced by Coriolis force and by dynamo models are of comparable order but different in sign. Therefore, they may compete, yielding in smaller active regions mainly the sign of helicity in accord with hemispheric sign rule (helicity and twist in Northern/Southern hemispheres of the Sun are predominantly negative/positive). For larger active regions the overall sign is probably reversed, so the same is expected for average tilts of bipolar groups. The helicity and tilt in sunspots also varies with the magnitude of the solar cycle. For tilt, the most important property found is that it appears odd with latitude dependence with a small additional contribution which is even with latitude, so it is systematically different from zero level at the equator. These theoretical estimates are compared with available observations of tilt of bipolar active groups in solar photosphere.

**Marion Weinzierl, Francois Bocquet, Anthony Yeates**

Durham University

*Effect of non-potential coronal boundary conditions on solar wind prediction*

We investigate the effect that non-potential simulations of the solar corona have on the predicted solar wind speed at Earth. Our coronal simulation is driven by Air Force Data Assimilative Photospheric Flux Transport (ADAPT) synoptic B_\rho maps as input at the photosphere. The simulated magnetic field is extrapolated using the Schatten Current Sheet method from the outer boundary of the inner corona at 2.5 solar radii R_{sun} to 21.5 R_{sun}. Here, the boundary conditions for the solar wind software Enlil are computed using an empirical solar wind formula based on the distance from the coronal hole boundary. We compare our results to observational OMNI data. In addition to a visual comparison of the velocities and velocity distributions, the ability to predict high speed enhancements is considered as a quality criterion. The non-potential method accounts for more of the complex magnetic structure in the corona and therefore has a significant effect on the predicted wind speed. We are able to achieve reasonable prediction results with fewer free parameters than the WSA wind speed formula.

**James Threlfall**

University of St Andrews

*Particle acceleration due to coronal non-null magnetic reconnection*

While various topological features (e.g. 3D magnetic nulls and separators) have been inferred as likely sites of magnetic reconnection in the solar atmosphere, reconnection is not constrained
to solely take place at such sites. In a recent investigation, we studied the particle acceleration resulting from a magnetic reconnection model which causes an arcade of coronal magnetic field to twist and form an erupting flux rope. Crucially, this event takes place in the absence of common topological features where magnetic reconnection is often thought to occur. The results of gyro-averaged particle orbits of electrons and protons for this event can be compared and contrasted with other (often topologically-based) MHD models of magnetic reconnection, revealing several distinct characteristics. We will discuss these, together with aspects of our findings which (unexpectedly) reproduce some general observational features typically seen during two-ribbon flare events.

MATTHEW ALLCOCK
University of Sheffield

Magneto-acoustic waves in an asymmetric magnetic slab

Using an analytical approach, we derive the dispersion relation governing the propagation of magneto-acoustic waves along a magnetic slab of homogeneous plasma enclosed on its two sides by non-magnetic, semi-infinite plasma of different densities and temperatures, thereby generalising the classic symmetric magnetic slab model. The dispersion relation, unlike that of a symmetric magnetic slab, cannot be factorised into sausage and kink eigenmodes as these modes are coupled. We will illustrate the eigenmodes using 3D animations to demonstrate the change in character of symmetric sausage and kink modes when the slab is asymmetric, introducing the terms quasi-sausage and quasi-kink modes. An analytical expression is derived which gives the ratio of the amplitudes of oscillation on each boundary of the slab as a function of the external density ratio and the parameters of the waveguide system. The results provide a novel tool for solar magneto-seismology and allow the determination of the magnetic field strength, which is traditionally difficult to measure, in inhomogeneous structures such as magnetic bright points and sunspot light bridges.
Invited Talk.

**Gherardo Valori**
University College London

*Magnetic helicity estimations in models and observations of the solar magnetic field*

In this talk I will present the results of the first benchmark of several finite-volume methods in estimating magnetic helicity in 3D test models, performed by a dedicated ISSI International Team on Magnetic Helicity. In addition to finite volume methods, two additional methods are also included that estimate magnetic helicity based either on the field line’s twist, or on the field’s values on one boundary and an inferred minimal volume connectivity. The employed model tests range from solutions of the force-free equations to 3D magneto-hydrodynamical numerical simulations. Almost all methods are found to produce the same value of magnetic helicity within few percent in all tests. However, methods show differences in the sensitivity to numerical resolution and to errors in the solenoidal property of input fields. In addition, a brief account of the search for an eruptivity proxy based on magnetic helicity will also be discussed.

Session 4 - Astrophysical.

**Amit Seta, Anvar Shukurov, Andrew Snodin, Paul Busby, Toby Wood**
Newcastle University

*Effect of magnetic field intermittency on cosmic ray diffusion*

Cosmic rays, highly energetic charged particles, are an important component of the interstellar medium (ISM) in galaxies as they have energy density close to the thermal gas, turbulence and magnetic fields. The cosmic rays diffuse through the ISM both due to the random walk of magnetic field lines and scattering by magnetic waves. The propagation of cosmic rays is usually analyzed in Gaussian random fields. However, spatial intermittency is unavoidable in interstellar medium due to compression by random shocks and fluctuation dynamo action. We study the propagation of cosmic rays in random and intermittent magnetic field generated by the fluctuation dynamo. The presence of magnetic field intermittency significantly enhances cosmic ray diffusion in a certain range of energies. The results are interpreted in terms of a correlated random walk. Infact, we obtain that the cosmic rays below a certain energy, always perform a correlated random walk rather than the usual Brownian motion.

**Felix Sainsbury-Martinez, Matthew Browning, Mark Miesch, Nick Featherstone**
University of Exeter

*Anelastic models of fully-convective stars: differential rotation, meridional circulation and residual entropy*

Low-Mass stars are typically fully convective, and as such their dynamics may differ significantly from sun-like stars. Here we present a series of 3D anelastic MHD simulations of fully convective stars, designed to investigate how the meridional circulation, the differential rotation, and entropy are affected by both varying stellar parameters, such as the luminosity or the rotation rate, and by the presence of a magnetic field. We also investigate, more specifically, a theoretical model in which isorotation contours and residual entropy ($\sigma' = \sigma - \sigma_r$) are intrinsically linked via the thermal wind equation (as proposed in the Solar context by Balbus in 2009). We have selected our simulation parameters in such a way as to span the transition between Solar-like differential rotation (fast equator + slow poles) and ‘anti-Solar’ differential rotation (slow equator + fast poles), as characterised by the convective Rossby number and $\Delta \Omega$. We illustrate the transition from single-celled to multi-celled MC profiles, and from positive to negative latitudinal entropy gradients. We show that an extrapolation involving both TWB and the $\sigma' / \Omega$ link provides a reasonable estimate for the interior profile of our fully convective stars. Finally, we also present MHD simulations which exhibit an almost unsuppressed differential rotation profile, with energy
balances remaining dominated by kinetic components.

Konstantinos Gourgouliatos  
University of Leeds  

3-D simulations of relativistic astrophysical jets  
Active Galactic Nuclei power jets that reach high Lorentz factors ($\Gamma \sim 20$) and contain sufficient energy to outshine their host galaxy. Several such jets demonstrate flaring behaviour: while they are narrow and collimated close to the origin, they undergo a stage of rapid expansion and their overall structure becomes disordered after a few kiloparsecs. In this talk, I will present simulations of jet evolution. I will use initial conditions of axially symmetric jets in equilibrium to investigate the development of instabilities. While these jets suffer minimal changes when used to initialise axially symmetric simulations, they are significantly disrupted due to Rayleigh-Taylor instability when full 3-D simulations are performed. I will discuss the implications of these results in the context of jet observations.

Session 5 - Solar 3.

Chris Lowder, Anthony Yeates  
Durham University  
Magnetic flux rope identification and characterization from observationally-driven solar coronal models  
Magnetic flux ropes are commonly defined as bundles of solar magnetic field lines, twisting around a common axis. Their evolution and potential eruption is of critical importance for space weather applications. Here a methodology is defined for the automated detection and tracking of flux rope structures within a simulation volume. Driving a magnetofrictional model using observed bipole observations, simulated flux ropes are detected over the span 15 June 1996 - 10 February 2014. Over this solar-cycle length span, flux rope footprints are mapped out, following cyclical trends in latitudinal distribution. Magnetic flux and helicity contained within flux rope footprints are quantified and compared over the span of the simulation. Separating the set of detected flux ropes into eruptive and non-eruptive, we consider the statistics of each set. With a methodology in place for flux rope detection, future work and applications are laid out for applying this methodology to additional simulated datasets.

Daniela Weston, David Hughes, Steven Tobias  
University of Leeds  
Magnetic buoyancy instability in the solar tachocline  
A layer of field is considered for insight into the magnetic buoyancy instability in the solar tachocline, with the mean field dynamo theory velocity pumping ($\gamma$) and turbulent diffusion ($\beta$) effects included. Initially, static equilibrium was considered and magnetic field profiles sought that would be stable under the $\gamma$ and $\beta$ effects. This was with the goal of providing a self-consistent basic state field for a linear stability analysis, taking into consideration the effects arising from mean field theory. Under these assumptions, the induction equation becomes a second order linear ODE with coefficients depending on the forms of $\gamma$ and $\beta$. Various profiles for $\gamma$ and $\beta$ were considered, subject to several different sets of two-point boundary conditions. Following this, $\gamma$ and $\beta$ effects were temporarily excluded and magnetic buoyancy effects alone were considered. Linear stability to interchange modes, and then to 3D modes, was investigated numerically. Spectral accuracy was provided by using Chebyshev differentiation matrices to construct the linear operators, working on a Chebyshev grid. Ongoing and future work involves adding $\gamma$ and $\beta$ effects to the linear stability analysis and combining with the corresponding equilibrium basic states, and finding the stability of the layer around a self-consistent basic state given these effects.
Ben Snow
University of Sheffield
Observational signatures of a kink-unstable coronal flux rope using Hinode/EIS
The signatures of energy release and energy transport for a kink-unstable coronal flux rope are investigated via forward modelling. Synthetic intensity maps are generated from a 3D numerical simulation. The CHIANTI database is used to compute intensities for three Hinode/EIS emission lines that cover the thermal range of the loop. The intensities at simulation resolution are spatially degraded to the Hinode/EIS pixel size (1") and convolved using a Gaussian point-spread function (3"), and exposed for a characteristic time of 50 seconds. The synthetic images generated for rasters (moving slit) and sit-and-stare (stationary slit) are analysed to find the signatures of the twisted flux and the associated instability. We find that there are several qualities of a kink-unstable coronal flux rope that can be detected observationally using Hinode/EIS, namely the growth of the loop radius and the increase in intensity towards the radial edge of the loop. However, EIS cannot resolve the small, transient features present in the simulation, such as sites of small-scale reconnection.

David Pontin
University of Dundee
Energy release in braided coronal loops
I will examine the dynamics of coronal loops containing non-trivial magnetic field line braiding, in the context of Parker’s braiding mechanism for coronal heating. The existence of braided force-free equilibria will be discussed, including a demonstration that these equilibria must contain current layers whose thickness decreases for increasing field complexity. The implication for the corona is that if one considers a line-tied coronal loop that is driven by photospheric motions, then the eventual onset of reconnection and energy release is inevitable. Once the initial reconnection event is triggered a turbulent relaxation ensues. The properties of this relaxation will be discussed, together with the expected observational signatures of energy release in such a braided coronal loop.

David MacTaggart
University of Glasgow
Optimal energy growth in current sheets
Tearing current sheets are important for many aspects of astrophysical MHD. However, the growth rate for the onset of the tearing instability is normally very slow compared to the time scale of the process to which the current sheet is associated, e.g., a flare. In this talk, we discuss the potential for transient growth, not accounted for in normal-mode analysis, to produce much faster growth rates for the onset of the tearing instability. Initial results suggest that the effect of transient growth can significantly increase the growth rate of the tearing instability, compared to that calculated from normal-mode analysis.

Chris McCabe, Steve Tobias
University of Leeds
The thin shell MHD equations and the solar dynamo
The thin shell MHD equations were derived to model the solar tachocline, and are appropriate for models of stably stratified dynamics with magnetic fields as, for example, might be used to describe the dynamics of the tachocline. We shall use these to investigate the development of MHD and differential rotation instabilities (so-called joint instabilities). They have been able to generate two instabilities: the clamshell instability, which is generated from an initial broad magnetic field; and the tipping instability, which is generated by an initial banded magnetic field where the latitude and strength of the bands can be varied. We shall investigate the role of Froude number and field strength on the form of the instability, paying particular attention to the generation of an electromotive force to be incorporated into subsequent mean field models.
Session 6 - Models and Methods.

Peter Wyper, Spiro K. Antiochos, C. Richard DeVore
Durham University

*A universal model for solar eruptions from coronal mass ejections to jets*

We present a model for solar eruptions that encompasses coronal mass ejections at one end of the scale, to coronal jets at the other. The model is a natural extension of the magnetic breakout mechanism for large-scale CMEs to the much smaller events of coronal jets. We show using high-resolution adaptive mesh MHD simulations conducted with the ARMS code that so-called blowout or mini-filament coronal jets can be explained as one realisation of the breakout mechanism in the particular magnetic topology of a closed field region separated from open field by a null point atop a domed separatrix surface. The inference is that as this topology is altered to become the four-flux closed field system needed to produce large-scale breakout CMEs, the associated eruptions will vary to account for different kinds of eruptions ranging from jets, to confined jets (jets along coronal loops), to confined flares to eruptive flares with CMEs. P.F.W was supported in this work by an award of a RAS Fellowship and an appointment to the NASA Postdoctoral Program. C.R.D and S.K.A were supported by NASA’s LWS TR&T and H-SR programs.

Daniel Miller
University of Exeter

*Alignment as an indicator of changes to modal structure within the Roberts flow*

Alignment of the velocity and magnetic fields has been examined in a number of different contexts within MHD, some of which include; turbulence, mean field theory, nonlinear dynamo theory and the solar wind. It has been shown that nonlinear dynamos which saturate due to an alignment of velocity and magnetic field may do so at equipartition. In this presentation I will show how changes to the cross-helicity, a quantity measuring alignment, within kinematic dynamo theory can indicate a change in the magnetic field structure. I solve the induction equation at a large magnetic Reynolds number and show that a rapid change in cross-helicity can indicate a transition between large scale eddy like magnetic modes and magnetic field with a seperatrix like structure.

Eleanor Vickers
University of Sheffield

*MHD surface waves in an inclined field*

Here we present an investigation into the characteristics of magneto-acoustic surface waves propagating at a single density interface, in the presence of an inclined magnetic field. A dispersion relation is obtained and solutions are found for a small inclination angle. The inclination of the field renders the frequency of waves to be complex, where the imaginary part describes a weak damping or growth in amplitude. In the absence of dissipative processes the interface penetrated by an inclined homogeneous field becomes active, that is, the interface is able to radiate or accumulate energy leading to the modification in the amplitude of guided waves.

Simon Candelaresi
University of Dundee

*Magnetic field line tangling and topological entropy*

Mixing of two-dimensional flows or three-dimensional magnetic fields is quantified using the finite time topological entropy FTTE. Similar to the finite time Lyapunov exponent it quantifies the amount of mixing of the fluid or chaotic dynamics in the system. Here we present an efficient method on how to compute the FTTE for periodic magnetic fields, like in Tokamaks, or for time periodic two-dimensional flows. Our method is both precise and highly time efficient. To show case the method we apply it to such cases that describe tangled or twisted magnetic fields.
A comparison of forcing functions in magnetohydrodynamics

Direct numerical simulations allow us to follow the evolution of a turbulent flow without introducing any modelling. However, in forced simulations, a decision has to be made about the method of energy injection. We present the results of a numerical analysis of incompressible, homogeneous magnetohydrodynamic turbulence without a mean magnetic field, subject to different kinetic forcing functions. The functions we use are representative of the range of forcing methods used in the literature, specifically: negative damping (which feeds the large scales of the field back into itself), a nonhelical random force, and a nonhelical deterministic sinusoidal force (analogous to helical ABC forcing).

We examine the time evolution of the three ideal invariants (energy, magnetic helicity and cross helicity); the energy spectra; and compare the magnetic energy and dissipation fractions at different Reynolds numbers. We also consider how the box size and Reynolds number affect the performance of the forcing function. We find that all three forces produce qualitatively similar steady states with some minor differences. The magnetic helicity is well-conserved in all cases but the sinusoidal method of energy injection has a tendency to introduce cross helicity into the system. Indeed, our results for sinusoidally-forced simulations with identical parameters and slightly different initial conditions show large variations in the normalised cross helicity over long time periods. It is important to monitor and control the injection of the ideal invariants since they can influence the system into Alfvénic, force-free or Beltrami states.

MHD waves and instabilities in a steady magnetic slab in an asymmetric environment

We investigate the propagation of linear MHD waves, and the occurrence of the Kelvin-Helmholtz instability, along a magnetic slab in an asymmetric environment. We define the equilibrium as an infinite magnetic slab embedded in a plasma with different values of pressure, density, and temperature on either side. A steady flow and constant magnetic field are present in the slab interior. We derive the dispersion relation for this system and analyse the effect of asymmetry of the equilibrium on the wave propagation along the slab. The threshold for the occurrence of the Kelvin-Helmholtz instability is obtained numerically, along with phase diagrams for the system. Applications to solar and magnetospheric physics are outlined.
Withdrawn.

Oleg Kirillov
Northumbria University

Singular diffusionless limits of double-diffusive instabilities in magnetohydrodynamics

We study local instabilities of a differentially rotating viscous flow of electrically conducting incompressible fluid subject to an external azimuthal magnetic field. In the presence of the magnetic field the hydrodynamically stable flow can demonstrate non-axisymmetric azimuthal magnetorotational instability (AMRI) both in the diffusionless case and in the double-diffusive case with viscous and ohmic dissipation. Performing stability analysis of amplitude transport equations of short-wavelength approximation, we find that the threshold of the diffusionless AMRI via the Hamilton-Hopf bifurcation is a singular limit of the thresholds of the viscous and resistive AMRI corresponding to the dissipative Hopf bifurcation and manifests itself as the Whitney umbrella singular point. A smooth transition between the two types of instabilities is possible only if the magnetic Prandtl number is equal to unity, $Pm=1$. At a fixed $Pm>1$ or $Pm<1$ the threshold of the double-diffusive AMRI is displaced by finite distance in the parameter space with respect to the diffusionless case even in the zero dissipation limit. The complete neutral stability surface contains three Whitney umbrella singular points and two mutually orthogonal intervals of self-intersection. At these singularities the double-diffusive system reduces to a marginally stable system which is either Hamiltonian or parity-time (PT) symmetric.

Kelig Aujogue, B. Sreenivasan, A. Pothrat
Coventry University

Experimental modeling of the Earth tangent cylinder

We present an experimental study of the convection within the region of the Earth liquid core, the Tangent Cylinder (TC). Until now, experimental studies were mainly focussing on rotating convection outside the TC and were often neglecting the crucial role played by the magnetic forces. For the first time, our experiment reproduces the interplay between Coriolis force, Buoyancy force and Lorentz force. Our study was conducted for Elsasser numbers $\Lambda$ (ratio of the Lorentz force to the Coriolis force) from 0 to 1, Ekman numbers $E$ (ratio of the viscous force to the Coriolis force) from $10^{-4}$ to $10^{-5}$ and the geophysics Rayleigh number $Ra_{geo}$ (ratio of the Buoyancy force over the diffusion) from $10^2$ to $10^4$. The Lorentz force was reproduced by permeating a strong electrolyte ($H_2SO_4$) with a high magnetic field. This novelty for deep earth study allowed us to conduct Particle Image Velocimetry (PIV) measurements. Hence, we were able to recover quantitative values for the vector field with parameters close to the onset of convection, and up to 20 times supercritical. Our results show that the magnetic field promotes fatter convective structures with stronger uplifting velocity near onset in very good agreement with theory for plane magnetoconvection.
List of participants

(1) Abrar Ali - City, University of London
(2) Matthew Allcock - University of Sheffield
(3) Mihai Barbulescu - University of Sheffield
(4) Oliver Bardsley - University of Cambridge
(5) Alexei Borissov - University of St Andrews
(6) Gert Botha - Northumbria University
(7) John Brooke - self-employed consultant
(8) Paul Bushby - Newcastle University
(9) Simon Candelaresi - University of Dundee
(10) Long Chen - ETH Zurich
(11) Grace Cox - University of Liverpool
(12) Peter Davidson - University of Cambridge
(13) Ryan Edgar - Northumbria University
(14) Cetin Can Evirgen - Newcastle University
(15) Robertus von Fay-Siebenburgen - University of Sheffield
(16) Andrew Gilbert - University of Exeter
(17) Konstantinos Gourgouliatos - University of Leeds
(18) Celine Guervilly - Newcastle University
(19) Chris Hales - Newcastle University
(20) Gareth Hawkes - University of Exeter
(21) Alexander Hindle - Newcastle University
(22) James Hollins - Newcastle University
(23) Gunnar Hornig - University of Dundee
(24) Thomas Howson - University of St Andrews
(25) David Hughes - University of Leeds
(26) Lewis Ireland - University of Exeter
(27) Dan Johnson - Northumbria University
(28) Chris Jones - University of Leeds
(29) Mouloud Kessar - University of Leeds
(30) Kirill Kuzanyan - IZMIRAN, Russian Academy of Sciences
(31) Juraj Kyselica - Geophysical Institute of the Czech Academy of Sciences
(32) Linh Le Phuong - Northumbria University
(33) Yufeng Lin - University of Cambridge
(34) Chris Lowder - Durham University
(35) Fionnlagh Mackenzie Dover - University of Sheffield
(36) David MacTaggart - University of Glasgow
(37) Joanne Mason - University of Exeter
(38) Christopher McCabe - Leeds University
(39) Mairi E McKay - University of Edinburgh
(40) Daniel Miller - Exeter University
(41) Ross Pallister - University of Dundee
(42) Jamon Pennicott - University of Warwick
(43) David Pontin - University of Dundee
(44) Jane Pratt - University of Exeter
(45) Christopher Prior - Durham University
(46) Jamie Quinn - University of Glasgow
(47) Avishek Ranjan - University of Cambridge
(48) Thomas Rees-Crockford - Northumbria University
(49) Stephane Regnier - Northumbria University
(50) Jack Reid - University of St Andrews
(51) Luiz Felippe Rodrigues - Newcastle University
(52) Felix Sainsbury-Martinez - University of Exeter
(53) Graeme Sarson - Newcastle University
(54) Roger Scott - University of Dundee
(55) Amit Seta - Newcastle University
(56) Juie Shetye - Armagh Observatory
(57) Anvar Shukurov - Newcastle University
(58) Valeria Shumaylova - University of Cambridge
(59) Lara Silvers - City, University of London
(60) Ben Snow - University of Sheffield
(61) Andrew Soward - Newcastle University
(62) Robert Teed - University of Cambridge
(63) Hope Thackray - University of Sheffield
(64) James Threlfall - University of St Andrew's
(65) Ajay Tiwari - Northumbria University
(66) Gherardo Valori - University College London
(67) Eleanor Vickers - University of Sheffield
(68) Xing Wei - Shanghai Jiao Tong University
(69) Marion Weinzierl - Durham University
(70) Daniela Weston - University of Leeds
(71) Tim Whitbread - Durham University
(72) Josh Wiggs - Northumbria University
(73) Fryderyk Wilczynski - University of Leeds
(74) Toby Wood - Newcastle University
(75) Peter Wyper - Durham University
(76) Anthony Yeates - Durham University