ABSTRACTS

Accretion very near black holes - slim accretion disks
Marek Abramowicz

I will discuss models of slim accretion disks and compare them with most recent MHD simulations. I will argue that the semi-analytic slim disk models provide an excellent description of black hole accretion flows, especially very near black holes.

Protostellar disks
Philip Armitage

Protostellar disks are the accreting systems where the prospects for dramatically improved observational constraints on turbulence and angular momentum transport are the best. I will review some of the physics particular to prostellar disks, where non-ideal MHD terms play a major role. This led to the idea of a dead zone of suppressed turbulence, and more recently to the possibility that the MRI leads to solutions which transport angular momentum through laminar stresses or winds. I will discuss some of the challenging open issues: how does the MRI interact with gravitational instability in massive disks, whether it is possible to tap the independent reservoir of thermal energy to drive turbulence, and how to reconcile the large net magnetic fluxes that are predicted from star formation with the much smaller fluxes that are sufficent to drive accretion via the MRI.

Non-linear evolution of the MRI in the presence of net vertical magnetic flux
Xuening Bai

Accretion disks are very likely threaded by external magnetic flux, inherent from disk formation, yet we are only at the beginning to explore the physical consequences. I will discuss recent simulations of the MRI in the presence of weak and strong external vertical magnetic field, highlighting the results on angular momentum transport, disk outflow, and magnetic flux transport. Limitations of the local approximation and future perspectives will also be discussed.

Nonmodal Growth of the Magnetorotational Instability and the Dynamo Effect

Amitava Bhattacharjee

Beyond its role as a prime mechanism for angular momentum transport in astrophysical disks, the magnetorotational instability (MRI) has now become a standard model for the study of MHD stability of rotating systems with sheared flows and a large-scale dynamo. In this talk, I will present some recent results (obtained in collaboration with Jonathan Squire) of the dynamo in turbulence induced by the MRI in its simplest possible form --- an unstratified shearing box without a mean magnetic field. Sustained turbulence --- generating a strong azimuthal magnetic field --- is possible in this system, despite the absence of spectral linear instability. Because of this, nonmodal growth due to the non-normality of the linear operator plays an important role in the MRI dynamo, both for axisymmetric and non-axisymmetric disturbances. With the goal of understanding the core dynamo process, we have been studying a quasi-linear version of the shearing box system, drawing upon interesting new developments in hydrodynamics. Among the most interesting ideas resulting from this approach is the existence of a mean field dynamo instability of homogenous background turbulence. The instability saturates nonlinearly at levels consistent with nonlinear simulations and depends strongly on the magnetic Prandtl number.

Hysteresis in Black Hole Binary State Transitions

Mitch Begelman

In X-ray binaries, the transition from hard to soft state typically occurs at a higher luminosity than the transition from soft to hard. Recent work has suggested that such hysteresis can result from the sensitivity of MRI-driven turbulence (and thus the value of alpha) to such disk properties as magnetic Prandtl number or net magnetic flux. Phil Armitage and I have been studying the latter possibility, and I will discuss our results to date.

Visualizing MRI turbulence through Compton ccattering

Omer Blaes

While MRI turbulence is generally subsonic, in the radiation pressure dominated flows of high luminosity accretion onto black holes, the turbulent velocities can exceed the sound speed in the gas alone, and even exceed the microscopic thermal speeds of both ions and electrons. In this regime, Compton scattering between photons and electrons will be dominated by the bulk motions of the turbulence, rather than thermal motions of the electrons. Bulk Comptonization by the turbulence can therefore have a direct impact on the radiation spectrum, and I will present calculations demonstrating this effect.

Instability, magnetism, and differential rotation in fully convective stars
Matthew Browning

In stars like the Sun, the interface between the convective envelope and the radiative core has been widely thought to play a crucial role in generating organized, cyclical magnetic fields. But sufficiently low-mass stars (as well as pre-main sequence and sub-stellar objects) are convective throughout their interiors, and so presumably do not possess such an interface; a generic theoretical expectation has therefore been that such stars should harbor magnetic dynamos very different from those in solar-like stars. I will discuss how this expectation has been partly borne out, but partly confounded, by recent observations and theoretical modeling of dynamos in fully convective stars. In particular, I will review 3-D MHD simulations of convection and magnetism in such stars, and highlight how the dynamo process in these models depends on rotation rate and stellar mass. Finally, I will also describe some of the impact the dynamo-generated magnetism has on flows and heat transport.

The Solar tachocline: a shallow-water perspective
James Cho

I shall review turbulence in the traditional shallow-water model and its MHD extension. focus will be on conservation laws and changes caused by the addition of the magnetic field -- in particular, on how inverse cascade-induced jet formation is modified. Possible application of the simple model to the solar tachocline is discussed.

Heating and cooling processes in the (diffuse and neutral) ISM
Bruce T. Draine

At constant density, the temperature of the gas in the diffuse neutral ISM is the result of the competition between heating processes that add heat to the gas, and cooling processes that remove it. The heating is generally thought to be dominated by elastic scattering of energetic electrons ejected from H and He by cosmic rays or X-rays, or electrons ejected from nanoparticles (dust grains) by ultraviolet photons. Some additional heating comes from energetic H2 molecules produced by catalytic formation of H2 on dust, photoionization of atoms other than H or He, photoexcitation and photodissociation of molecules, and gradual damping of MHD turbulence and waves, but these are normally estimated to be of secondary importance.

Cooling of the gas - removal of thermal energy - occurs by excitation of atoms, ions, and molecules by inelastic scattering of thermal electrons and atoms, followed by radiative decay of the excited states. Additional cooling due to inelastic collisions of gas particles with colder dust grains is generally unimportant, except in very dense regions.

Balancing heating and cooling allows us to understand the range of temperatures in the diffuse neutral ISM, including the coexistence of a cool phase and a warm phase at the same pressure.

There is, however, evidence (which will be reviewed) that diffuse molecular clouds often contain regions where the gas temperature is much higher than expected based on balancing the above-cited heating and cooling processes. The clear implication is that additional heating processes are present, capable of transforming either mechanical or magnetic energy into heat.

Intermittency of interstellar turbulence : a new playground for theorists, observers and numericists

Edith Falgarone

Turbulence in galaxies stands at the crossroad of a wide variety of cosmic processes, including star formation and stellar feedback. As such, it is key in the self-regulation of the open cycle of matter and energy, mainly powered by stars, that keeps the interstellar medium (ISM) far out of thermodynamic equilibrium. A fundamental property of turbulence was recognized in the early 1960's: its intermittency in space and time. Since then, intermittency has been observed and characterized in laboratory flows and the terrestrial atmosphere.

Magnetic fields and compressibility of the ISM make turbulent intermittency more elusive. Yet, statistical studies start to be significant and slowly disclose its properties. Some of the first steps of chemistry in the diffuse ISM that have been known for decades to require supra-thermal energy, can now be understood in the framework of turbulent intermittency. Unexpectedly, chemistry is therefore providing unique diagnostics and tracers of the energy trail in ISM turbulence.

Thermodynamics of the dead zone inner edge in protoplanetary disks
Julien Faure

In protoplanetary disks, the inner boundary between an MRI active and inactive region has recently been suggested to be a promising site for planet formation, thanks to the trapping of solid at the boundary itself or in vortices generated by the Rossby Wave instability.
However, numerical models of the boundary have so far considered only the case of an isothermal equation of state while the disk thermodynamics and the turbulent dynamics are entwined because of the thermal ionization.
Using the Godunov code RAMSES, we have performed a 3D global numerical simulation of a protoplanetary disk, including thermodynamical effects and a simple model for the resistivity dependence with temperature. The comparison with a 2D viscous simulation has been extensively used to identify the physical processes at play.
We find that, surprisingly, a vortex forming at the interface migrates inward, penetrates inside the active zone until beeing destroyed by turbulent motions. A new vortex forms few tens of orbits later at the interface and migrates too.
In this paper, we characterize this vortex life cycle and discuss its implications for planet formation at the dead/active interface.

Radiation MHD In Global Simulations Of Protoplanetary Disks.
Mario Flock

In this talk we present our newest results related to the thermal and dynamical evolution of gas and dust in turbulent protoplanetary disks.
We developed a radiative transfer module, based on the flux-limited diffusion approximation that includes frequency dependent irradiation and dust opacities. We present results of the first global 3D radiation magneto-hydrodynamic simulations of a stratified protoplanetary disk. The simulation parameters are chosen to approximate those of the system AS 209 in the star-forming region Ophiuchus. We start the simulation from a disk in radiative and hydrostatic equilibrium.
The magneto–rotational instability quickly causes magneto–hydrodynamic turbulence and heating in the disk. The disk midplane temperature raises to a new equilibrium. A roughly flat vertical temperature profile establishes in the disk's optically thick region. The present work demonstrates for the first time that global radiation magneto–hydrodynamic simulations of turbulent protoplanetary disks are feasible with current computational facilities. This opens up the windows to a wide range of studies of the dynamics of protoplanetary disks, especially their inner parts for which there are significant observational constraints.

Recent progress in numerical modeling of accretion flows
Charles F. Gammie

The discovery of the magnetorotational instability in 1991 initiated a flurry of numerical investigations into its nonlinear evolution that continue to this day. I will review recent work on the saturation of disk turbulence, particularly disk turbulence around black holes, describe some upcoming relevant observations, and point out some outstanding problems for future investigation.

Meteorite evidence for sequential star formation in a hierarchichal ISM.
Matthieu Gounelle

Short-lived radionuclides are radioactive elements with half-life significantly shorter than the age of the Solar System. Their decay products can be found in meteorites indicating that some of them such as 26Al (T1/2 = 0.74 Myr) or 60Fe (T1/2 = 2.6 Myr) were alive in the nascent Solar System. I will review the proposed origin for short-lived radionuclides, and show that the past presence of 26Al and 60Fe in the nascent Solar System can be attributed to massive stars and trace sequential star formation in a hierarchical ISM. I will specifically focus on the last episode of star formation that lead to our Sun formation in a dense shell accumulated around a massive star.

The physics of the MRI
John F. Hawley

Disk accretion is one of the most fundamental processes in the universe. Extensive observations have revealed a wide range of astrophysical phenomena in which accretion plays a significant, or even fundamental, role. The magnetorotational instability (MRI) provides the root mechanism by which accretion occurs. This talk will review the basic physics of the MRI, as well as present some (now) historical recollections of the research that Steve Balbus and I carried out to discover and elucidate the properties of this instability.

Chondrules: Our eyes in protoplanetary disks
Emmanuel Jacquet

Primitive meteorites provide irreplaceable constraints on the conditions of our past protoplanetary disks. They consist in agglomerations of various millimeter-sized solids native to the solar nebula, in particular the ubiquitous chondrules, which are silicate spherules presumably resulting of transient high-temperature episodes in the disk. Yet despite their ubiquity, and the wealth of data gathered on them -- e.g. age range, physico-chemical conditions of formation, individual paleomagnetic records etc. --, the nature of their formation mechanism, obviously an important process in the disk, remains elusive. I will discuss some recent advances in the field, and the (even more numerous!) questions they raise.

Angular Momentum Transport in the Lab
Hantao Ji

This talk is to summarize rigorous efforts in the lab to demonstrate and study the mechanisms of rapid angular momentum transport relevant to accretion disks, including the MRI. Isolating and minimizing effects due to artificial boundaries, which are inherent to terrestrial experiments, has been a particular challenge. Nonetheless, significant insights relevant to accretion disks have been already obtained, with many surprises, perhaps even to Steve. The recent achievements and future prospects of these efforts will be discussed in this talk in three categories: hydrodynamic, magnetohydrodynamic, and gas/plasma experiments.

Hydrodynamic stability of disks
Hubert Klahr

Keplerian disks have proven to be extremely stable to perturbations, when magnetic fields are not in operation. But disks around young stars are complicated entities, very similar to planetary atmospheres. There is a radial temperature gradient driven by stellar irradiation, which leads to a thermal wind, e.g. vertical shear. The temperature gradient leads also to a height dependent radial stratification that can be radially buoyant. Without thermal relaxation these disks are stable, but with the right amount of cooling and heating for instance by the radiative transport of heat, one can drive a Goldreich-Schubert-Fricke Instability (see for instance Nelson et al 2013) or a Convective Overstability (Klahr and Hubbard 2014; Lyra 2014). In this talk I discuss some recent results from linear stability analysis and numerical experiments.

From MRI turbulence to photons
Julian Krolik

MHD turbulence driven by the MRI accounts for the internal stress driving accretion; it also implies dissipation capable of supplying the energy for the photons we observe. In recent years, it has become possible to combine numerical simulations of accretion dynamics with radiation transfer techniques to predict the photon output of accretion in a manner nearly free of phenomenological models. This talk will review a number of results that have emerged, focusing on the case of accretion onto black holes. MHD processes turn out to have interesting, and sometimes surprising, consequences for the thermal, coronal, and fluorescence components in terms of their luminosity, spectrum, variability, and polarization.

How to tap free-energy gradients with anisotropic diffusion

Matthew Kunz

Much of Steve's published work throughout the 1990s and early 2000s focused on the curious ability of magnetic fields to replace conserved-quantity gradients with free-energy gradients as the discriminating quantities of stability. That they do so not just dynamically -- the most prominent example being the MRI -- but also passively -- by placing stringent constraints on the nature of viscous, resistive, and conductive flows -- lends further credence to what has become one of Steve's classic mantras, that "even the tiniest of magnetic fields can have dramatic consequences for the macroscopic stability of astrophysical plasmas." In this talk, I will review a veritable alphabet soup of free-energy-gradient instabilities driven by anisotropic diffusion, focusing on both the mathematical similarity of their dispersion relations and the impact they might have on astrophysical systems. These include shear instabilities in poorly ionized gas driven by ambipolar diffusion and the Hall effect, as well as magneto-viscous forms of convection and rotational instability in weakly collisional plasmas.

Revisiting the linear MRI in quasi-global geometries

Henrik Latter

The mathematical physics of the linear ideal MRI is particularly well trodden territory. Indeed the lucid early treatment of Balbus & Hawley (1991, 1998, etc) in the local and slow limit has become canonical: the introduction to almost any research talk on accretion disks would seem incomplete without a reference to fluid blobs, magnetic tethers, and mechanical springs. In my talk, however, the linear ideal MRI will not be limited to the introduction. I will be focusing on the linear theory throughout, revisiting attractive, and overlooked, results in global geometries: vertically stratified boxes and cylindrical disk models. The MRI in both cases exhibits (a) the local incompressible dispersion relation, despite the global nature of the modes, (b) convenient analytic approximations to the global eigenfunctions, and (c) channel flows that remain approximate nonlinear solutions until the plasma beta approaches one.

Thanatology in protoplanetary discs

Geoffroy Lesur

The existence of magnetically driven turbulence in protoplanetary discs has been a central question since the discovery of the magnetorotational instability (MRI). Early models considered Ohmic diffusion only and led to a scenario of layered accretion, in which a magnetically ``dead'' zone in the disc midplane is embedded within magnetically ``active'' surface layers at distances of about 1--10 au from the central protostellar object. Recent work has suggested that a combination of Ohmic dissipation and ambipolar diffusion can render both the midplane and surface layers of the disc inactive and that torques due to magnetically driven outflows are required to explain the observed accretion rates.
In this talk, I will present recent results revisiting this problem including all three non-ideal MHD effects: Ohmic diffusion, Ambipolar diffusion and the Hall effect. I will show in particular that the Hall effect can ``revive'' dead zones by providing a large scale magnetic torque in the disc midplane, potentially leading to significant accretion rates. Implications for the global evolution of protoplanetary discs will be discussed.

The role of magnetic fields in star formation

Christopher McKee

Magnetic forces in the diffuse interstellar medium are much greater than the forces due to self-gravitation, thereby precluding star formation there. Historically, it has been conjectured that ambipolar diffusion, in which neutral molecules contract relative to the magnetized ions, is essential for allowing gravitational forces to exceed magnetic forces in star-forming clouds. However, observations of magnetic field strengths in molecular cloud cores have failed to find evidence of cores that are magnetically dominated. Analysis of Zeeman observations of magnetic fields in molecular cloud cores sheds light on the intrinsic distribution of field strengths. It is also possible to use ideal magnetohydrodynamic (MHD) simulations to "observe" a turbulent molecular cloud on a computer. Such simulations provide the full 3D field and show how tangling of the field lines reduces the field measured by the Zeeman effect. Magnetic fields are effective at extracting angular momentum from the gas accreting onto a protostar, and many simulations have found that protostellar (and therefore protoplanetary) disks cannot form in the presence of observed interstellar magnetic fields. When turbulence is included, however, rotating protostellar disks can indeed form in the presence of magnetic fields, suggesting that ideal MHD in the presence of turbulence is not ideal.

As the Sun turns: Differential rotation and meridional circulation in stellar convection zones

Mark Miesch

The solar differential rotation (DR) is among the most fundamental and enduring problems in astrophysical fluid dynamics. Its discovery dates back to the mid 19th century when Sir Richard Carrington was able to map the latitudinal variation of the solar surface rotation by tracking sunspots, revealing the fluid nature of the solar interior. Modern measurements using various observing techniques closely match Carrington's result, indicating that the solar DR has not changed by more than a few percent in over 150 years. Though the story of the solar DR is not complete, the plot has thickened in the last three decades. The helioseismology revolution has revealed the internal rotation profile of the Sun as increasingly sophisticated supercomputer models unravel the nonlinear dynamics of solar convection, mean flows, and magnetism. These advances are supplemented by continuing stellar observations and theoretical insights (including those by our man of honor) that contribute perspective and context. One of the realizations from this work is that the DR is intimately linked dynamically with the meridional circulation (MC) and that both are intimately linked to solar magnetism. In particular, it is the MC that may set the pace of the 11-year solar cycle. I will review our current understanding of the solar DR and MC and how this understanding extends to other stars. Highlights include the solar near-surface shear layer, potential pitfalls of mean-field modeling, and the "convection conundrum": why recent observational and modeling results are challenging our understanding of convective heat and angular momentum transport.

Planetesimal and planet migration and growth in turbulent disks

Richard P. Nelson

Turbulence in protoplanetary discs can have a profound influence on the formation and evolution of planets. Turbulent density fluctuations can act as a source of stochastic forcing that excites the eccentricities and inclinations of planetesimals and planets, influencing their collisional outcomes. The stochastic forcing also introduces a random walk component to the orbital evolution, influencing planetary migration and the radial mixing of planetesimals. Furthermore, the angular momentum transport associated with disc turbulence may provide the effective viscous stress needed to prevent the saturation of the corotation torques experienced by low mass planets, and drives the gas accretion onto forming giant planets, as well as their type II migration. In this talk I will review recent work that has examined these issues, and discuss how recent developments in our understanding of protoplanetary disc dynamics may influence the theory of planet formation.

Dynamics and instability of eccentric discs
Gordon Ogilvie, Adrian Barker

Eccentric accretion discs composed of variably elliptical Keplerian orbits are found in many binary stars and can also be formed when stars or planets are tidally disrupted. Their dynamics is potentially an important aspect of planet disc interaction. We formulate a local model of an eccentric disc that generalizes the shearing sheet to include the elliptical geometry of the reference orbit and the oscillatory compression associated with an eccentricity gradient. Stresses computed in the local model feed into the equations determining the large-scale evolution of the shape and mass distribution of the disc. Eccentric discs lack vertical hydrostatic equilibrium and undergo nonlinear vertical oscillations that can become extreme for eccentricities above about 0.5. The associated stresses significantly modify the behaviour of eccentric discs from two-dimensional models. We compute these solutions and their linear stability to locally axisymmetric disturbances. Inertial waves are parametrically destabilized with growth rates that are significantly larger than in two-dimensional models. The nonlinear outcome of this instability may generate hydrodynamic activity in astrophysical discs and limit the eccentricities that can be achieved.

New forms of convection & turbulence: The MTI & HBI in galaxy clusters
Ian Parrish

I will review the discovery of the magnetothermal instability (MTI) by Steve Balbus and its subsequent study from early numerical work through current simulations of the MTI in galaxy clusters. This fascinating instability taps into the temperature gradient as a source of free energy (as opposed to the entropy gradient in Schwarzschild convection). I will explain the linear and nonlinear physics as well as the saturation process of the instability. In the outer part of the intracluster medium, the MTI driven by the outwardly decreasing temperature gradient can drive vigorous convection. The resultant non-thermal pressure support from this vigorous convection has direct implications for using SZ measurements of clusters in cosmological surveys. Finally, I will also mention the closely-related heat-flux-driven buoyancy instability (HBI) that also operates in clusters and discuss its possible effect in driving bimodality in cluster cores.

Topology and magnetic field strength in spherical an elastic dynamo simulations

Ludovic Petitdemange

Numerical modelling of convection driven dynamos in the Boussinesq approximation revealed fundamental characteristics of the dynamo-generated magnetic fields and the fluid flow. Because these results were obtained for an incompressible fluid of constant density, their validity for gas planets and stars remains to be assessed. A common approach is to take some density stratification into account with the so-called anelastic approximation.

The validity of previous results obtained in the Boussinesq approximation is tested for anelastic models. We point out and explain specific differences between both types of models, in particular, with respect to the field geometry and the field strength.

Our investigations are based on a systematic parameter study of spherical dynamo models in the anelastic and Boussinesq approximations.

The dichotomy of dipolar and multipolar (oscillatory) dynamos identified in Boussinesq simulations is also present in our sample of anelastic models. Dipolar models require that the typical length scale of convection is an order of magnitude larger than the Rossby radius. However, the distinction between both classes of models is somewhat less explicit than in previous studies. This is mainly due to two reasons: we found a number of models with a considerable equatorial dipole contribution and an intermediate overall dipole field strength. Furthermore, a large density stratification may hamper the generation of dipole dominated magnetic fields. Previously proposed scaling laws, such as those for the field strength, are similarly applicable to anelastic models. It is not clear, however, if this consistency necessarily implies similar dynamo processes in both settings. We discuss how these findings relate to previous models and to stellar and planetary observations.

An accretion disc instability induced by a temperature sensitive alpha parameter
Will Potter

The thin disc alpha parameter is usually assumed to be a constant in analyses, however, from both theoretical considerations and simulations we expect alpha to be variable. I will show that if alpha is not a constant but depends on the magnetic Prandtl number (as suggested by simulations) it can produce an instability in the disc. This instability generates cyclic flaring in the inner disc which could help to explain the complicated flaring behaviour of observed X-ray binary systems.

Convection in galaxy cluster plasmas
Eliot Quataert

The outer parts of galaxy clusters are unstable to the magnetothermal instability if the temperature decreases at large radii. I summarize the physics that sets the temperature gradients in galaxy clusters, the saturation of the magnetothermal instability, and its implications for galaxy cluster plasmas.

Accretion in (initially) unmagnetized collisionless plasmas
Eliot Quataert

We study the stability and angular momentum transport in initially unmagnetized collisionless plasmas. Conceptually, this bridges the gap between hydrodynamic, magnetohydrodynamic, and magnetized kinetic models of disk dynamics and transport. We show that initially unmagnetized rotating collisionless plasmas are unstable to electromagnetic instabilities (specifically, the Weibel instability). This leads to the generation of a magnetic field and outward transport of angular momentum. The stress is dominated by the anisotropic pressure contribution (i.e., "collisionless viscosity"). The amplification of the magnetic field saturates with a cyclotron frequency somewhat larger than the disk rotation frequency, leaving the plasma in a state that is likely unstable to the MRI. This mechanism may be important for the astrophysical origin of magnetic fields at high redshift.

The Physics of the Intracluster Medium and AGN feedback in galaxy clusters

Christopher Reynolds

In the central regions of cooling-core galaxy clusters, the activity of a central active galactic nucleus (AGN) is generally believed to heat the intracluster medium (ICM), thereby preventing a cooling catastrophe and the unchecked growth of the central galaxy — these systems provide the cleanest environments to observe AGN feedback at work. However, the actual physical processes involved in this AGN-cluster feedback are complex and subtle. The actual physical process by which the AGN-injected energy is thermalized remains unknown and is almost certainly associated with plasma-scale processes. Equally mysterious is the mechanism by which the AGN is fueled (on parsec scales) at a rate that is fine-tuned to balance cooling in the ICM core (on 100kpc scales). Finally, even the background ICM atmosphere is dynamically complex, with conduction-driven MHD instabilities driving turbulence from the free-energy in the background temperature gradient. In this talk, I shall summarize the current observational constraints, as well as today's theoretical challenges and progress, on AGN-cluster feedback models.

The dark side of the accretion disk dynamo

François Rincon, A. Riols, C. Cossu, G. Lesur, G. I. Ogilvie, P.-Y. Longaretti

Even though the magnetorotational dynamo ("zero net-flux" MRI) has long been considered one of the possible bootstrapping processes of turbulent angular momentum transport in accretion disks, whether it can actually be excited in Keplerian shear flow in the astrophysically relevant regime of magnetic Prandtl number $Pm \ll 1$ very much remains an open question. I will present an overview of recent collaborative research aiming at deciphering the challenging dynamical complexity of this subcritical dynamo transition. I will first show that the emergence of three-dimensional chaos and transient MHD turbulence in this problem is primarily associated with global homoclinic and heteroclinic bifurcations involving the stable and unstable manifolds of three-dimensional nonlinear MRI dynamo cycles born out of saddle node bifurcations. I will then explain how such solutions may be harnessed to learn more about the physics of the transition as a whole, and will present new results indicating that turbulent magnetic diffusion makes the excitation and sustainment of the dynamo at moderate magnetic Reynolds number Rm increasingly difficult for decreasing Pm, resulting in an increase of the critical Rm of the dynamo for increasing kinematic Reynolds number Re, in agreement with earlier numerical results. The potential implications of these results for the accretion disk dynamo will finally be discussed.

Stratified turbulence in galaxy cluster cores

Alex Schekochihin, Irina Zhuravleva, Eugene Churazov, Federico Mogavero, Scott Melville, Matt Kunz, Francois Rincon, Steve Cowley

I will discuss some basic properties of stratified turbulence in galaxy cluster cores and the implications for what's observed. In particular, what's observed quite well is density fluctuations across a decent scale range, whence one can make inferences about the turbulence and, therefore, about energy dissipation rates in cluster cores. I will review some recent work on this subject [1,2,3]. I will then discuss various schemes for the evolution of the magnetic field in a weakly collisionless plasma [4]: what we have learned recently [5,6,7] and what that might imply for the role of magnetisation in the dynamics and thermodynamics [8] of cluster cores.

References:

[1] I. Zhuravleva et al., ApJL, in press (2014) arXiv:1404.5306

[2] E. Churazov et al., MNRAS 421, 1123 (2012)

[3] I. Zhuravleva et al., "Turbulent heating in the brightest galaxy clusters" (to appear)

[4] F. Mogavero and A. A. Schekochihin, MNRAS 440, 3226 (2014)

[5] M. W. Kunz et al., PRL 112, 205003 (2014)

[6] S. Melville and A. A. Schekochihin, "Magnetic field evolution in a Braginskii plasma" (to appear)

[7] F. Rincon et al., "Nonlinear mirror instability in weakly magnetised anisotropic plasmas" (to appear)

[8] M. W. Kunz et al., MNRAS 410, 2446 (2011)

Observational signatures of MRI-driven turbulence in protoplanetary disks: Connecting numerical simulations with ALMA

Jacob Simon

Protoplanetary disks play a key role in star and planet formation processes. Turbulence in these disks, which arises from the magnetorotational instability (MRI), not only causes accretion of mass onto the central star, but also sets the conditions for processes such as dust settling, planetesimal formation, and planet migration. However, the exact nature of this turbulence is still not very well constrained in these systems.

In this talk, I will describe new work, utilizing both state-of-the-art numerical simulations and high resolution radio observations, to directly link numerical predictions for the turbulent velocity structure of protoplanetary disks to observations by the Atacama Large Millimeter Array (ALMA). ALMA's unprecedented resolution will allow us to generate a three-dimensional view of disk turbulence by measuring the turbulent broadening component of molecular lines at different disk heights and radii. A direct comparison between the observed turbulence values and those obtained from simulations will strongly constrain our theoretical understanding of these disks and the conditions under which planetary systems develop.

Numerical models of the MRI: Past, present, and future.
James M. Stone

I will review some of what we have learned about the nonlinear regime of the MRI from numerical simulations. I will start at the beginning, with the first two-dimensional results published by Hawley & Balbus in a companion paper to the linear analysis presented in the MRI discovery paper. I will then highlight some of the important discoveries made through simulations since then, including results from the first three-dimensional simulations, the first vertically stratified models, and the first fully global models. I will summarize what we have learned as additional physics has been added, including finite dissipation, non-ideal MHD, and radiation transport. Many of these topics continue to be the focus of current research, and I will give a brief overview of some of the important problems and puzzles being addressed in current work. Finally I will highlight some challenges for the future.

Magnetic Wreaths and Dynamo Cycles in Sun-like Stars
Juri Toomre

The building and cycling of global-scale magnetic fields in turbulent convection envelopes of stars like the Sun involve many dynamical elements, with rotation and shear figuring prominently. Using 3-D MHD global simulations with our Anelastic Spherical Harmonic (ASH) code, our studies have revealed that remarkable wreaths of strong magnetic field can be built in the bulk of the convection zone by dynamo action. These wreaths possess toroidal fields often with opposite polarity in the two hemispheres, with some of the field pumped downward into the tachocline to be further amplified by shear. The sense of the magnetic fields can reverse over decade-long time scales. Some models that had gone through many reversing cycles even went into brief quiescent intervals like a Maunder Minimum, and then resumed their cycling. Further, we have obtained loops of magnetic field that break off spontaneously from the wreaths and rise toward the surface, providing a path for flux emergence. All of these processes involve sensitive balances between magnetic field amplification and dissipation that occur over a range of scales, with multi-scale interactions being critical to the field evolution.

Transition to turbulence in Couette and Poiseuille flows
Laurette Tuckerman

Shear flows, i.e. Couette and Poiseuille flows, become turbulent for Reynolds numbers at which they are linearly stable. Although this transition is not completely understood, a number of advances have been made in recent years. For transitional Reynolds numbers, the flow takes the form of coexisting laminar and turbulent regions whose geometric, statistical and dynamical properties are now well characterized. Critical Reynolds numbers have been defined probabilistically and determined numerically. The force balance between the turbulent and laminar regions has elucidated the maintenance of the coexistence regimes.

A connection between the MRI and Elastodynamics
Geoffrey Vasil

I will present a new simple model for the MRI in a weakly nonlinear regime. Conducting a systematic reduction of the full problem with reasonable simplifying assumptions leads to a particularly simple nonlinear dispersive wave equation governing the dynamics of the instability near onset. Surprisingly, the reduced dynamics corresponds to that of an elastic buckling beam under an applied load. This very simple reduced model helps explain the saturation of the MRI via flux and momentum conservation principles with direct analogies to transport of compression and tension stress in a bent elastic rod. I will briefly discuss possible applications of this model to the dynamics of the solar near-surface shear layers, and magnetic dynamo.

Magnetic drift in molecular cloud cores, protoplanetary discs, and the solar chromosphere
Mark Wardle

Flux-freezing breaks down under the low levels of ionisation in molecular cloud cores and protoplanetary discs. The dominant processes are ambipolar diffusion and hall drift, which enable slippage of magnetic flux through the predominantly neutral gas. The nature of the field line drift through the bulk neutral component of the gas is as important as its magnitude. Under ambipolar diffusion, magnetic field lines in the direction of the local magnetic stress; the drift is accompanied by dissipation associated with collisions between charged and neutral species. The Hall effect introduces a drift perpendicular to the local magnetic stresses that is unaccompanied by dissipation. Hall drift dominates ambipolar diffusion over a wide range of radii in protoplanetary disks and likely plays a significant role during gravitational collapse of cloud cores. I shall outline the physics underlying magnetic drift in a partially ionised medium and then discuss applications to gravitational collapse, magnetorotational instability and jet acceleration in protoplanetary discs. Similar considerations also apply on small scales in the partially-ionised solar chromosphere.