The origin of magnetic fields in astrophysical rotators is commonly studied separately from the dynamical astrophysical role that the resulting magnetic fields play. Here I will discuss how the origin and the function of the fields are in fact coupled both in stars and disks. To exemplify this, I will discuss a new simple “holistic” model of stellar spin down and X-ray luminosity that couples to dynamo theory and shows promise toward explaining a range of observations. On the same theme, I will discuss why large scale dynamos may be fundamental to the dynamics of accretion disks and why accretion disk theory and large scale dynamo theory are actually artificially separated components of what should be a single theory.
Large-scale dynamo action describes the process of magnetic flux generation. It is commonly believed that at high magnetic Reynolds numbers the conservation of magnetic helicity plays an important role in determining the final efficiency of the dynamo process. In particular, in a closed system, the need to conserve helicity may cause the dynamo to saturate at low levels. This has led to the belief that in order to generate substantial flux, the dynamo region should be magnetically open so that helicity can be readily expelled from the region of field generation. Although this idea has many attractive features, its general validity is difficult to assess quantitatively. The problem is that in an open system, the helicity is not gauge invariant. Thus one is faced with a dilemma: to replace the helicity with some other quantity that is gauge invariant but that may be unrelated to dynamo action, or to pick a specific gauge with the attendant need to justify that particular choice.

I shall argue that in some cases it is possible to justify a particular choice of gauge on physical grounds. Having done so, I will show that with this choice all ambiguities in the measurements of helicity and helicity fluxes are removed. I will show results in which this procedure is applied to numerical simulations of dynamo action driven by the magneto-rotational turbulence.
One of the major unanswered questions related to neutron stars is the origin of the exceptionally high magnetic fields hosted by magnetars, which can reach $10^{15}$ G. Recent observations of magnetars also suggest that the intensity of the magnetic field varies by at least an order of magnitude on their surface, confirming that simple dipolar fields are far from being realistic approximations and leading to additional puzzles regarding the smaller scale structure of the field. I will be presenting 3-D simulations of the evolution of the crustal magnetic field, mediated by the Hall effect. These simulations demonstrate that the evolution under the Hall effect leads to unstable behaviour creating “magnetic spots” with sizes of a few kilometers. The magnetic fields in these regions are one order of magnitude stronger than the large scale dipole field, accelerating Ohmic dissipation, and providing sufficient heat accounting for magnetars’ X-ray luminosities. The strong Maxwell stresses generated can lead to crust yielding and trigger magnetar bursts. Thus, magnetar theory becomes more economical, as localized strong magnetic field form spontaneously out of a weaker large scale field.
“Characterizing the Mean-field Dynamo in Turbulent Accretion Disks”

The formation and evolution of a wide range of astrophysical objects is governed by gradual accumulation of mass through a surrounding, rotationally-supported cloud of gas. Interpreting observational signatures emanating from such accretion discs entails accurate modelling of the underlying physical processes. Yet models that go beyond a simple parametrisation have remained elusive for more than four decades. The aim of this project is to devise a new accretion disc model which properly subsumes our current knowledge about instabilities in magnetised rotating shear flows. A key aspect in this endeavour is the role played by the disc's internal dynamo in setting the degree of magnetisation. Aided by state-of-the-art numerical simulations, the goal is to nurse an intuitive understanding of the disc “microphysics”. Such intuition can then inform the design of simplified models needed to study secular evolution.
Céline Guervilly

Large-scale vortex dynamos in rotating convection

Recent computational studies have described the formation of large-scale vortices in rotating turbulent convection in planar geometry. These vortices, which are long-lived and depth-invariant, form by the merger of convective thermal plumes. In this talk, I will show that for magnetic Reynolds numbers below the threshold for small-scale dynamo action, such flows can sustain large-scale magnetic fields - i.e. fields with a significant component on the scale of the system.
Title:  
the MRI dynamo in the Hall regime  

Abstract:  
The dynamics of the MRI dynamo is known to be highly sensitive to nonideal MHD effects. However, most of the studies to date have focused on Ohmic and viscous diffusion. During this presentation, I will introduce the first results of the MRI dynamo in the Hall-dominated limit, a regime relevant to some parts of protoplanetary discs. I will show that a transition in the dynamo behaviour appears when the Hall characteristic length becomes larger than the disc scale height. In this new dynamo regime an organised poloidal field is spontaneously produced and sudden bursts of turbulence are observed. I will show that this transition and these bursts can be understood with a simple, yet powerful, mean field model.  

Geoffroy Lesur
Revisiting the role of helicity in magnetohydrodynamic dynamos
Pablo D. Mininni
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CONICET, Argentina

Symmetry properties of physical systems govern their behaviour, and are associated with
conservation of physical quantities in the ideal case. In magnetohydrodynamics, the absence of
mirror symmetry in the flow (i.e., the presence of mechanical helicity) results in the growth of
large scale magnetic fields through dynamo action. The importance of helicity for the dynamo is
well understood, although its possible origins and its impact in other properties of the flow is still
under debate. In this talk I will discuss possible sources of helicity in astrophysical flows, and the
effect of mechanical helicity in the partition of energy among modes, and in the emergence of
coherent structures that can be beneficial for dynamo action. Then, I will revisit the transfer of
helicity among scales as a result of dynamo action, and the impact mechanical helicity has on
long-term statistical properties of magnetohydrodynamic flows.
Collisionless plasma dynamo

François Rincon (joint work with F. Califano, A. A. Schekochihin and F. Valentini)

While magnetic field amplification in magnetohydrodynamic fluids has been thoroughly studied over the last fourty years, the dynamo effect in weakly collisional plasmas has comparatively received little attention, in spite of its potential relevance for high energy astrophysics and cosmology. In this talk, I will present the first 3D-3V Vlasov-Maxwell numerical simulations of a turbulent dynamo in a stochastically-driven non-relativistic flow of collisionless plasma, and describe the main properties of this dynamo in regimes that can be probed with current computational means. I will finally discuss the potential implications of the results for cosmic magnetogenesis and cluster magnetic fields, and future directions of research on this problem.
The hallmark of magnetic relaxation in an RFP plasma is profile flattening of $J_0 \cdot B_0/B^2$ effected by a dynamo-like emf in Ohm’s law. This is well-studied in single-fluid MHD, but recent MST results and extended MHD modeling show that both $<V_1 \times B_1>$ and the Hall emf, $-<\mathbf{J}_1 \times \mathbf{B}_1>/en_e$, are important, revealing decoupled electron and ion motion. Since dynamo is current-related, the electron fluid emf, $<V_{e,1} \times \mathbf{B}_1>$, captures both effects. In MST, the electron flow is dominantly $V_{e,1} \approx E_1 \times B_0/B^2$, implying $<V_{e,1} \times \mathbf{B}_1> \approx <E_1 \cdot \mathbf{B}_1>/B$. This and the Hall emf are measured in MST for comparison in Ohm’s law. A finite-pressure response is also possible, e.g., “diamagnetic dynamo”, $\nabla \cdot <p_{e,1}B_1>/en_e$, associated with diamagnetic drift, and “kinetic dynamo” associated with collisionless streaming of electrons in a stochastic magnetic field. Correlation measurements $<n_{e,1}B_{r,1}>$ and $<T_{e,1}B_{r,1}>$ using FIR interferometry and Thomson scattering reveal these as small but finite in MST. A kinetic emf might be expected for any high-beta plasma with inhomogeneous pressure. Support by DOE/NSF.
Magnetic fields in the multi-phase interstellar medium: statistical analysis

Anvar Shukurov
Newcastle University, UK

ABSTRACT
The interstellar medium (ISM) in spiral galaxies is a site of turbulent dynamo action that produces both large-scale and small-scale magnetic fields. This is an unusual dynamo system since the ISM is highly inhomogeneous: three pervasive gas phases are identified as (1) the hot, dilute gas, (2) warm, partially ionized gas and (3) cool, dense gas clouds. The hot gas is fully ionized; it occupies about 20% of the volume near the galactic midplane. Most of the ISM volume (80%) is occupied by the warm gas, whereas the gas clouds have a negligible volume fraction but contain 90% of the gas mass. This complex structure is produced by energy injection from supernova stars that also drive a system of random shock fronts travelling through the ISM.

We discuss properties of the mean and random magnetic fields in the multi-phase ISM, as obtained from fully nonlinear, non-ideal MHD simulations. Magnetic and velocity fields are separated into the mean and random parts using Gaussian smoothing adapted to satisfy the Reynolds rules of averaging. The correlation properties of magnetic, velocity and density fields in each phase, and their variation with position above the galactic midplane, are presented, compared and discussed. In order to identify the phase(s) that hosts the mean-field and fluctuation dynamos, we derive and analyse the probability distributions of magnetic line lengths in the ISM phases, for both the mean and random magnetic fields. For the first time, we have obtained conclusive and quantitative evidence that the mean-field dynamo resides in the warm phase of the ISM.
The magnetic shear-current effect: generation of large-scale magnetic fields by small-scale dynamo

A new mechanism for turbulent mean-field dynamo is proposed and explored, in which homogenous magnetic fluctuations resulting from a small-scale dynamo drive the generation of large-scale magnetic fields. This is in stark contrast to the common idea that small-scale magnetic fields should be harmful to large-scale dynamo action. These dynamos occur in the presence of large-scale velocity shear and do not require net helicity, resulting from off-diagonal components of the turbulent resistivity tensor as the magnetic analogue of the "shear-current" effect. The effect has been analyzed using direct numerical simulation, novel quasi-linear statistical simulation techniques, and analytic calculations, and is likely to be particularly important for turbulence in the central regions of accretion disks.
The DRESDYN project: Theoretical background and planned experiments

Frank Stefani, Helmholtz-Zentrum Dresden-Rossendorf

The DREsden Sodium facility for DYnamo and thermohydraulic studies (DRESDYN) is a platform for large scale experiments related to geo- and astrophysics as well as to various industrial liquid metal applications. The most ambitious parts of DRESDYN are a homogeneous hydromagnetic dynamo driven solely by precession, and a large Tayler-Couette type experiment for the combined investigation of the magnetorotational instability (MRI) and the Tayler instability (TI). We present recent numerical results on precession driven flows in cylinders and their dynamo action. We also discuss some new theoretical results on various versions of the magnetorotational instability and the Tayler instability, including magnetically triggered instabilities of rotating flows with positive shear. The progress of the construction of the DRESDYN building and of the design of the various experiments is delineated.
Modeling the convective turbulent dynamos of stars

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Global convective dynamo simulations have exhibited in the past decade a rich variety of magnetic self-organization, from small-scale turbulent fields; stable magnetic structures; to periodically reversing large-scale magnetic fields. These promising results were obtained using various ways to treat the small, sub-grid scales, that are thought to play an important (albeit unclear) role in the large-scale organization of the magnetic field of stars. A careful cross-comparison on the effect of the treatment of the subgrid-scales is hence required today to estimate the robustness of these various results.

We report here on an ongoing effort to characterize the influence of small-scales in numerical models of stellar dynamos. We first give a brief tour of the present status of non-linear dynamo simulations in stellar convection zones. We then focus on results obtained using implicit large eddy simulations (ILES) for a solar-like, cyclic, turbulent dynamos. In particular, we investigate the development of magnetohydrodynamical instabilities in the underlying stable zone, which participate in setting the period of the magnetic cycle. We then focus on an ongoing benchmarking effort, which aims to compare convective turbulent dynamo solutions obtained with large eddy simulations (LES) and implicit-LES (ILES) using the ASH and EULAG codes. The goal is to assess the exact effect of the subgrid-scales treatment on the large-scale organization, for each of these methods. We present an original spectral method we developed on a typical hydrodynamic simulation of stellar convection to estimate the dissipative properties of the ILES. We conclude by giving perspectives as to how extend our comparison methodology for magnetohydrodynamic solutions with a cyclic large-scale magnetic field.
Kandaswamy Subramanian

Title:
Challenges to large-scale dynamo action in high Rm astrophysical systems.

Abstract:
Astrophysical systems like stars and galaxies host large-scale magnetic fields, which are thought to arise by turbulent dynamo action. They are also large Rm systems, which raises two potential challenges. First, they need to get rid of small scale magnetic helicity which naturally arises during the generation of large-scale fields. Second, they have to come to terms with the more rapid generation of small-scale fields by the fluctuation dynamo. We discuss how both these problems are potentially overcome. In relation to the second challenge, we present evidence that one may rather have a unified large/small scale dynamo in helical turbulent systems.
Title: Large-scale dynamo waves at high Rm.

Abstract: In astrophysics, dynamo action takes place at high magnetic Reynolds number (Rm), which means different things to different people. In the limit of high Rm the dynamo must overcome its tendency to generate magnetic fields on the small (resistive) scales in order for large-scale fields to be observed. Here I shall discuss what it means to be at high Rm, and argue that large-scale fields can only be observed if some process can be found that suppresses the small-scale dynamo. I shall further argue that understanding the statistics of the electromotive force (including the higher moments) is key to unravelling dynamo action at high Rm.

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Magnetic Helicity Flux and Large Scale Dynamos

Ethan T. Vishniac - Johns Hopkins University

Turbulence in a rotating environment causes a large scale flux of magnetic helicity. The consequent creation of domains of magnetic helicity leads to rapid growth of large scale magnetic fields. Comparing this to standard mean field dynamo theory we see that kinetic helicity is always negligible; that the dynamo growth rate diminishes as the large scale field becomes stronger, and that the eddy-scale magnetic helicity does not lead to alpha suppression, but is the prime mover of the dynamo process. I will show how this leads to a natural explanation for the amplitude of stellar magnetic fields as a function of Rossby number.
Large-scale flow generation in inhomogeneous hydrodynamic and magnetohydrodynamic turbulence
Nobumitsu Yokoi
Institute of Industrial Science, University of Tokyo

A primary effect of turbulence is enhancing effective transports, which are represented by notions such as eddy viscosity, eddy diffusivity, turbulent magnetic diffusivity, etc. described in terms of the turbulent energy or intensity. However, in some situations, turbulence may also work for suppressing the effective transport, leading to the large-scale structure formation or field generation in turbulence. In focusing on the flow generation, we investigate roles of the turbulent helicity and cross helicity (velocity--magnetic-field correlation) in inhomogeneous hydrodynamic (HD) and magnetohydrodynamic (MHD) flows.

In the HD flows, in addition to the eddy viscosity which is linked to the turbulent energy, the inhomogeneous turbulent helicity enters into the Reynolds-stress expression in combination with the large-scale vorticity or rotation, leading to the counter-balance effect against the transport enhancement due to the eddy viscosity coupled with the mean velocity strain. This is an effect of turbulence suppressing the effective transport, or in other words, represents the large-scale vorticity-generation due to turbulence. This inhomogeneous helicity effect in the HD turbulence was validated by a Reynolds-averaged turbulence model applied to the turbulent swirling flow, and recently have been validated with the aid of direct numerical simulations (DNSs) of a rotating forced turbulence.

In the MHD flows, turbulent transport of mean momentum is represented by the Reynolds and turbulent Maxwell stresses. As in the HD case, inhomogeneous turbulent helicity coupled with the large-scale vorticity may work for the suppression of momentum transport. Besides these stresses, the turbulent electromotive force contributes to the momentum transport through the mean-field Lorentz force. The turbulent cross helicity is expected to play a role in the transport suppression since in general it does not vanish in the mean-field Lorentz force. This is in strong contrast with the helicity or α effect, which gives a force-free field configuration, leading to no feedback to the mean momentum equation. These effects are discussed in the context of the solar torsional oscillation and magnetic reconnection.
“Shear-driven dynamos without the standard omega effect”

Fatima Ebrahimi

Unlike previous studies of large scale dynamos in differentially rotating flows, in which the mean field shear term (the "omega effect") is essential, here we show for the first time how the combination of imposed helical fluctuations and differential rotation, or linear shear of the fluctuating field, is sufficient to source the electromotive force and generate a large scale magnetic field in cylindrical geometry. For cylindrical differentially rotating plasmas threaded with a uniform vertical magnetic field, we study large-scale magnetic field generation from finite amplitude perturbations using analytic theory and direct numerical simulations. Analytically, we impose helical fluctuations, a seed field, and a background flow and use quasi-linear theory for a single mode. The predicted large-scale field growth agrees with numerical simulations in which the magnetorotational instability (MRI) arises naturally. The vertically and azimuthally averaged toroidal field is generated by a fluctuation-induced EMF that depends on differential rotation. Given fluctuations, the method also predicts large-scale field growth for MRI-stable rotation profiles and flows with no rotation but shear. The implication of this method for Hall dynamos will also be discussed.