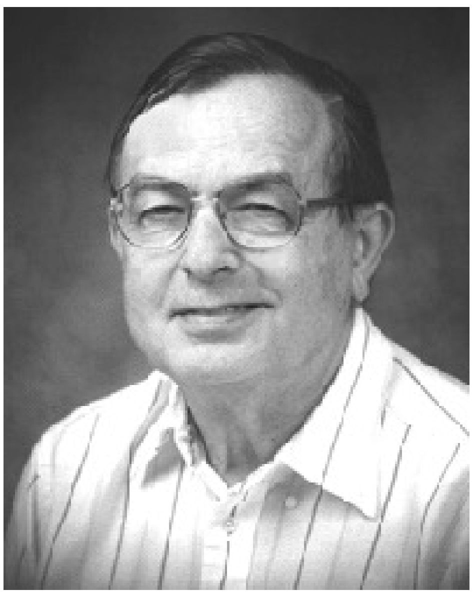
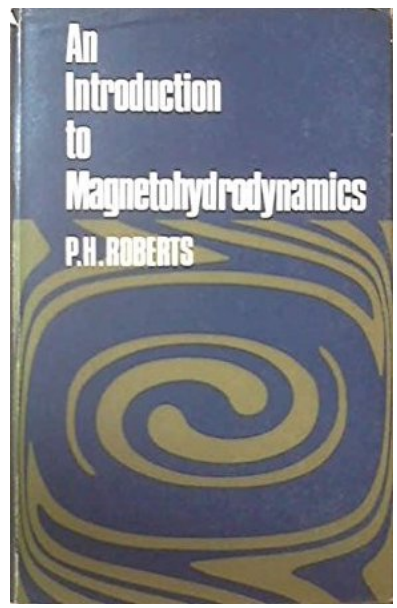
Fifty years after Roberts' MHD: Dynamos and planetary flows today

Book of Abstracts





Magnetostrophy

Cheng-chin Wu & Paul H. Roberts
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Abstract

A dynamo driven by motions unaffected by viscous forces is termed 'magnetostrophic', but cannot be found through today's numerical simulations, which require substantial viscosity to stabilize solutions of the full MHD dynamo equations. By using an alternative numerical technique, proposed by Taylor (1963, Proc. R. Soc. Lond., vol. 274, p. 274), we recently obtained the first magnetostrophic dynamo solutions ever derived (2015, GAFD, vol. 109, p. 84). These were axisymmetric and of mean-field type.

Taylor's magnetostrophic theory ignores inertial forces. Consequently, there are no torsional waves. We argued (2014, GAFD, vol. 108, p. 696) that torsional waves would be restored if inertial forces were added to Taylor's theory. In this presentation, we compare mean-field solutions derived using the original Taylor theory ('OTT') with those obtained from a modified Taylor theory ('MTT') in which inertial forces are not ignored.

New Analysis of Magnetic Tornadoes

Arter Wayne
UKAEA, Culham Science Centre, Abingdon

Abstract

The recent work[1] showed how the equations of ideal, compressible magnetohydrodynamics (MHD) may be elegantly formulated in terms of Lie derivatives, building on the work of Helmholtz, Walen and Arnold. The

"linear" fields approach reduces ideal MHD to a low order set of non-linear ordinary differential equations capable of further simplification, so has the potential to enrich understanding of this difficult subject, which has application both to laboratory and geophysical/astrophysical plasmas.

The just published work [2] extends the linear fields' solution of compressible nonlinear MHD to the case where the magnetic field depends on superlinear powers of position vector, usually but not always, expressed in Cartesian components. Implications of the resulting Lie-Taylor series expansion for physical applicability of the Dolzhansky-Kirchhoff (D-K) "linear field" equations are found to be positive. It is demonstrated how resistivity may be included in the D-K model. Arguments are put forward that the D-K equations may be regarded as illustrating properties of nonlinear MHD in the same sense that the Lorenz equations inform about the onset of convective turbulence. It is thereby suggested that the Lie-Taylor series approach may lead to valuable insights into MHD turbulence, especially fast timescale transients and the role of plasmoids.

1. Arter, W. 2013 "Potential vorticity formulation of compressible magnetohydrodynamics. Phys. Rev. Lett. 110, 015004." (doi:10.1103/PhysRevLett.110.015004)
2. Arter, W. 2017 "Beyond linear fields: the Lie–Taylor expansion",Proc. R. Soc. A473, 20160525; http://dx.doi.org/10.1098/rspa.2016.0525

On the Nature of Diffusion-Free Heat Transfer Scalings in Dynamo Models

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Abstract

Many dynamo studies extrapolate numerical model results to planetary conditions by empirically constructing scaling laws. The seminal work of Christensen and Aubert (2006) proposed a set of scaling laws that have been used throughout the geoscience community. These scalings make use of specially-constructed parameters that are independent of fluid diffusivities, anticipating that large-scale turbulent processes will dominate the physics in planetary dynamo settings. With these 'diffusion-free' parameterizations, the results of current numerical dynamo models are argued to extrapolate directly to fully-turbulent planetary core systems; the effects of realistic fluid properties merit no further investigation. Here, we will discuss the validity of diffusion-free heat transfer scaling arguments and their applicability to planetary conditions. We do so by constructing synthetic heat transfer datasets and examining their scaling properties alongside those proposed by Christensen and Aubert (2006). Our results show that the diffusion-free parameters compress and stretch the heat transfer data, eliminating information and creating an artificial alignment of the data. Most significantly, diffusion-free heat transfer scalings are found to be unrelated to bulk turbulence and are instead controlled by the onset of non-magnetic rotating convection, itself determined by the viscous diffusivity of the working fluid. Ultimately, our results, in conjunction with those of Stelzer and Jackson (2013) and King and Buffett (2013), show that diffusion-free heat transfer scalings are not validated by current-day numerical dynamo datasets and cannot yet be extrapolated to planetary conditions.

The Evolution of Magnetic-Coriolis Waves in Planetary Cores

Oliver Bardsley
University of Cambridge

Abstract

Motivated by dynamics in planetary cores, we consider the dispersion of waves from localised sources in a rapidly-rotating fluid threaded by a mean magnetic field.

We focus on the evolution of waves packets launched as *inertial-Alfvén waves*, which resemble low-frequency inertial waves, in the sense that energy disperses axially on the fast timescale of the background rotation rate, though they also exhibit slower propagation along magnetic field lines at the Alfvén velocity. When the magnetic field is uniform, inertial-Alfvén waves automatically focus energy radiation onto the rotation axis, ensuring that they dominate the dispersion pattern.

However, the situation changes when the mean magnetic field is non-uniform. The wave packets are forced to evolve into a more general form of magnetic-Coriolis wave, and hence refract off-axis. We show that the ultimate fate of any wave packet is strongly dependent on the choice of launch location, i.e. the strength of the magnetic field at the source.

Juno at Jupiter: Initial Magnetic Field Results

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Abstract

The Juno spacecraft entered orbit around Jupiter in July 2016. Every 53 days Juno passes close to Jupiter, spending about 2 hours travelling from above the north pole, at a radial distance from the center of Jupiter of approximately 2 Rj, to perijove near the equator at a radial distance of approximately 1.06 Rj, and then to above the south pole. Thus, with a nominal radius of the Jovian dynamo region of 0.85 Rj, Juno measures Jupiter's magnetic field proportionately much closer to its dynamo than is possible for any other planet.

By the end of October 2017, Juno will have completed eight passes separated by approximately 45 degrees of longitude, Initial data show that Jupiter has a spatially complex, intense magnetic field, with field strengths of almost 800,000 nT recorded during its first pass. Using an alternative method of magnetic field analysis based on an elastic net to model the field in physical space, the first pass revealed a strong pair of spots near the equator, suggestive of flux expulsion, and patches of reverse flux at high latitudes. Although subsequent orbits have not measured quite such strong fields as the first orbit, they nonetheless suggest considerable spatial complexity.

Jupiter and Saturn, the two gas giants in our solar system, have remarkably different magnetic fields. Understanding this difference is clearly a first order problem in planetary magnetic fields.

On effects of topography in rotating flows

Fabian Burmann
ETH Zürich

Abstract

Both, seismological studies and geodynamic arguments suggest that there is significant topography at the core mantle boundary (CMB). This leads to the question whether the topography of the CMB could influence the flow in the Earth's outer core. As a preliminary experiment, we investigate the effects of bottom topography in the so-called Spin-Up, where motion of a contained fluid is created by a sudden increase of rotation rate. Experiments are performed in a cylindrical container mounted on a rotating table and quantitative results are obtained with particle image velocimetry. Several horizontal length scales of topography (λ) are investigated, ranging from cases where λ is much smaller then the lateral extend of the experiment (R) to cases where λ is a fraction of R. We find that there is an optimal λ that creates maximum dissipation of kinetic energy. Depending on the length scale of the topography, kinetic energy is either dissipated in the boundary layer or in the bulk of the fluid. Two different phases of fluid motion are present: a starting flow in the from of solid rotation (phase I), which is later replaced by meso scale vortices on the length scale of bottom topography (phase II).

Balanced models for rapidly rotating convection-driven magnetohydrodynamics

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Abstract

Rotation is known to play a key role in the generation of planetary and stellar magnetic fields. Rapidly rotating dynamos are characterized by a leading order geostrophic force balance between the Coriolis and pressure gradient forces; inertia, viscosity and the Lorentz force can all perturb this balance and yield quasi-geostrophic (QG) magnetohydrodynamics. QG dynamos are routinely studied via direct numerical simulation of the magnetohydrodynamic equations, but remain computationally intensive due to the range of spatiotemporal scales. However, simplified, QG dynamo models can be developed via asymptotic reduction of the governing equations. These models offer significantly reduced computational complexity while simultaneously allowing for a simplified physical picture of the dynamics. A summary of the theoretical properties and results from ongoing numerical simulations of these reduced QG dynamo and magnetoconvection models will be discussed.

Geomagnetic polar minima do not arise from steady meridional circulation

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Abstract

Observations of the Earth's magnetic field have revealed locally pronounced field minima near each pole at the core-mantle boundary (CMB). The leading explanation for the existence of the polar magnetic minima has long been attributed to the supposed large-scale overturning circulation of molten metal in the outer core: fluid upwells within the inner core tangent cylinder toward the poles then diverges toward lower latitudes when it reaches the CMB, where Coriolis effects sweep the fluid into anticyclonic vortical flows. The diverging near-surface meridional circulation is believed to advectively draw magnetic flux away from the poles, resulting in the low intensity or even reversed polar magnetic fields. However, the inter- connections between magnetic minima and meridional circulations have not to date been ascertained quantitatively. Here we quantify the magnetic effects of steady, axisymmetric meridional circulation driven by Ekman and gyroscopic pumping. We numerically solve the axisymmetric magnetohydrodynamic equations for Earth's outer core under the magnetostrophic approximation, varying the amplitude of the thermal forcing, the imposed poloidal magnetic field amplitudes and geometries, and the kinematic viscosity of the fluid. Extrapolated to core conditions, our results show that the change in polar magnetic field resulting from steady, large-scale meridional circulations in Earth's outer core is less than 4% of the background field, significantly smaller than the 100% polar magnetic minima observed at the CMB. This suggests that the geomagnetic polar minima cannot be produced solely by axisymmetric, steady meridional circulations, and must depend upon additional tangent cylinder dynamics, likely including non-axisymmetric, time-varying processes.

Saturn's Internal Magnetic Field Revealed by Cassini Grand Finale

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Abstract

Saturn's internal magnetic field has been puzzling since the first in-situ measurements during the Pioneer 11 Saturn flyby. Cassini magnetometer measurements prior to the Grand Finale phase established 1) the highly axisymmetric nature of Saturn's internal magnetic field with a dipole tilt smaller than 0.06 degrees, 2) at least an order of magnitude slower secular variation rate compared to that of the current geomagnetic field, and 3) expulsion of magnetic fluxes from the equatorial region towards high latitude.

The Cassini spacecraft entered the Grand Finale phase in April 2017, during which time the spacecraft dived through the gap between Saturn's atmosphere and the inner edge of the D-ring 22 times before descending into the deep atmosphere of Saturn. The unprecedented proximity to Saturn (reaching ˜ 2500 km above the cloud deck) and the highly inclined nature of the Grand Finale orbits provided an ideal opportunity to decode Saturn's internal magnetic field. The fluxgate magnetometer onboard Cassini made precise vector measurements during the Grand Finale phase. Magnetic signals from the interior of the planet and various magnetospheric currents were observed during the Grand Finale phase. Here we report the magnetometer measurements during the Cassini Grand Finale phase, new features of Saturn's internal magnetic field revealed by these measurements (e.g., the high degree magnetic moments, the level of axisymmetry beyond dipole), and implications for the deep interior of Saturn.

Strong Field Spherical Dynamos

Emmanuel Dormy
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Abstract

Some 40 years ago Paul Roberts introduced the notion of weak and strong field branches for the Geodynamo. I will present numerical models recently obtained which illustrate this conjectured bifurcation diagram. Direct numerical simulations in a spherical shell can indeed exhibit the anticipated transition from a weak-field dynamo branch, in which viscous effects set the dominant length scale, and the strong-field branch, in which viscous and inertial effects are largely negligible.

In addition to the weak-dipolar branch and to the fluctuating-multipolar branch, widely discussed in the literature, a third regime can thus be identified.It corresponds to a strong-dipolar branch which appears to approach, in a numerically aordable regime, the magnetostrophic limit relevant to the dynamics of the Earth's core. I will discuss the transitions between these branches and point to the relevance to this strong-field dipolar branch to Geodynamo modelling.

I will finally argue that a distinguished limit needs to be sought to produce numerical models relevant to the geodynamo, and that the usual approach of minimising the magnetic Prandtl number (ratio of the fluid kinematic viscosity to its magnetic diffusivity) at a given Ekman number is misleading.

Experiments and simulations of the magnetized spherical Couette problem

Ferran Garcia
Helmholtz-Zentrum Dresden-Rossendorf

Abstract

The magnetized spherical Couette system models experiments that are being carried out at Helmholtz-Zentrum Dresden-Rossendorf (HZDR). A liquid metal is confined within two differentially rotating spheres and immersed in a magnetic field parallel to the axis of rotation. Preliminary simulations of periodic and quasiperiodic flows, arising at the first bifurcations, will be presented. The aim is to study in detail the instabilities observed in the experiments and previous numerical studies. This study will reveal how the flow patterns depend on control parameters, reproducing thus different physical situations of the HZDR experiments.

Simulations of dynamo action from a precession driven flow in a cylindrical container

Andre Giesecke
Helmholtz-Zentrum Dresden-Rossendorf

Abstract

Since many years precession is regarded as an alternative flow driving mechanism that may account, e.g., for remarkable features of the ancient lunar magnetic field or as a complementary power source for the geodynamo. Precessional forcing is also of great interest from the experimental point of view because it represents a natural forcing mechanism that allows an efficient driving of conducting fluid flows on the laboratory scale without making use of propellers or pumps. Within the project DRESDYN (DREsden Sodium facility for DYNamo and thermohydraulic studies) a dynamo experiment is under development at Helmholtz-Zentrum Dresden-Rossendorf in which a precession driven flow of liquid sodium with a magnetic Reynolds number of up to Rm=700 will be used to drive dynamo action.

Our present study addresses preparative numerical simulations and flow measurements at a small model experiment running with water. In dependence of precession ratio and Reynolds number the resulting hydrodynamic flow patterns and amplitudes provide the essential ingredients for kinematic dynamo models that are used to estimate whether the particular flow is able to drive a dynamo. In the strongly non-linear regime the flow essentially consists of standing inertial waves. Most remarkable feature is the resonant-like occurrence of a stationary axisymmetric mode which emerges around a precession ratio $\Omega_p/\Omega_c = 0.1$. Kinematic dynamo models applying the time-averaged flow from the hydrodynamic simulations exhibit dynamo action at a critical magnetic Reynolds number of Rm^{c}=430 which is well within the range that will be achieved in the planned sodium experiment.

Behaviors and transitions along the path to magnetostrophic convection

Alexander Grannan
UCLA, Los Angeles

Abstract

Turbulent convection constrained by Coriolis and Lorentz forces is important for generating planetary magnetic fields. Theoretical predictions suggest that the convective regime for planetary dynamos is a unique magnetostrophic state where Coriolis and Lorentz forces are the leading order balance. However, many experimental studies have focused only on rotating and non-rotating turbulent convection and relatively few laboratory experiments are capable of investigating turbulent magnetoconvection and the turbulent magnetostrophic regime. In this work, we perform one laboratory experiment in a cylinder at a fixed heat flux using the liquid metal gallium in order to investigate, sequentially: Rayleigh-Benard convection without any imposed constraints, magnetoconvection with a Lorentz constraint imposed by vertical magnetic field, rotating convection with a Coriolis constraint imposed by rotation, and finally the magnetostrophic convective regime. Using an array of internal and external temperature probes, we show that each regime along the path to magnetostrophic convection is unique. The behaviors and transitions in the dominant modes of convection as well as their fundamental frequencies and wavenumbers are investigated.

Dipole Oscillations and Stability of the Geodynamo

David Gubbins
University of Leeds

Abstract

Paleointensity studies have shown Earth's dipole moment continually fluctuates by about 40% of the mean during intervals of "stable" polarity: the dynamo never reaches stable equilibrium. Strong oscillations can arise from extreme sensitivity of the critical Ra at very low Ekman number. I have explored this with a series of numerical dynamo experiments in which only Ra, the Roberts number (q), and initial conditions, vary. Three regimes of dynamo action result: weak-field (Ra>RaD) and strong-field (Ra>RaS), depending on whether the initial field is weak or strong, and subcritical (Ra<RaD), when a weak initial field gives no dynamo but a strong initial condition does. At Ra> RaS the weak field energy increases exponentially to a critical point where it accelerates even faster to join the strong field branch. Exponential growth corresponds to a kinematic dynamo with little change to the fluid flow; the faster growth is accompanied by an increase in length scale measured by energy/dissipation. Increasing Ra further produces only a small increase in magnetic energy. The strong-field and subcritical dynamos have strong oscillations that decrease in size as Ra increases initially, then increase again at larger Ra as expected; they are associated with changes in length scale, as in the growth from weak- to strong-field dynamo action.

Large-scale flows and magnetic fields produced by rotating convection in a quasi-geostrophic model in spherical geometry

Céline Guervilly
Newcastle University

Abstract

We present numerical simulations of rotating Boussinesq convection at low Rossby numbers using a quasi-geostrophic (QG) model in spherical geometry. For low Prandtl numbers (Pr$\sim$O(0.1)) and low Ekman numbers (Ek<1e-6), the convection occurs on a "strong" branch, characterised by Reynolds numbers greater than 1000, that can extend well below the linear onset of convection (Ra$\sim$0.6Ra$_{crit}$ for Ek=1e-8 and Pr=0.01). These QG results hold in the 3D system for similar parameters as shown by the numerical study of Kaplan et al (2017 PRL 119). In this talk, we discuss the characteristics of the QG flows on the strong branch, such as the increase of the convective scale with the thermal forcing and the formation of intense zonal flows consisting of persistent multiple jets. These zonal flows strongly affect the convective heat transport, leading to the formation of a mean temperature staircase. We also show preliminary results of dynamos generated by the quasi-geostrophic flows at low magnetic Prandtl numbers.

Waves in spherical dynamo simulations and their implications for planetary dynamos

Kumiko Hori
Kobe University/University of Leeds

Abstract

Magnetohydrodynamic waves excited in deep interiors of rapidly rotating planets can produce secular time-variations of the magnetic fields. In strong-field dynamos, in which the inertial and viscous forces are small compared to the magnetostrophic forces (i.e. Coriolis, pressure, Lorentz, and buoyancy forces), unique wave motions can occur in both axisymmetric and nonaxisymmetric modes. Examples include torsional Alfven waves and magnetic Rossby waves. To explore the relevance of these waves and their dynamics, we use DNS of spherical dynamos driven by Boussinesq or anelastic convection. The linear theory gives good results for observed wave speeds, although nonlinear Lorentz terms were found to influence the waveforms. Waves in data, combined with theory, could allow us to infer physical properties within the Earth's core or Jupiter's metallic hydrogen region.

On the unique flow morphologies in rotating convection of liquid metals

Susanne Horn
UCLA, Los Angeles

Abstract

Rotating convection is one of the underlying fundamental processes occurring in the Earth's outer liquid metal core.
The low Prandtl number (Pr) that characterises liquid metals also implies that there are inherently different instability mechanisms present compared to moderate- or high-Pr fluids.
As a consequence, a distinct type of convection develops that is formed of large-scale oscillatory inertial modes.
To study the associated unique flow morphologies, we have conducted direct numerical simulations of rotating convection in a cylinder filled with a fluid with Pr=0.025 and rotating with Ekman numbers as low as 5×10^{-6}. The Rayleigh number (Ra) range was chosen in such a way that we could investigate the purely oscillatory regime close to onset, the mixed regime of oscillatory and wall modes, and also broad band turbulence. The obtained flow fields were analysed using the Dynamic Mode Decomposition (DMD). This technique allows to extract and identify the structures that govern the dynamics of the system as well as their corresponding frequencies.
We find that different types of oscillatory modes coexist, they can precess prograde and retrograde and also occur in the form of quasi-axisymmetric torsional modes. For higher Ra, they additionally couple and non-linearly interact with wall modes. Leveraging on these results we are in the progress of designing a dynamic observer, with the objective to connect our results to laboratory experiments. This will enable us to draw a complete picture of the multi-modal flow in low-Pr convection.

Torsional waves in a rotating spherical shell: transmission and reflection in the Earth's outer core

Dominique Jault
University Grenoble Alpes / CNRS

Abstract

I will discuss 1D models and solutions for torsional Alfvén waves in a spherical shell. Transmission at the tangent cylinder and reflection at the equator have not been fully elucidated yet. There are interesting analogies with waves in a canal of abruptly varying depth and with motions of a string with frictional support at one end. The solution in the equatorial region in the presence of a magnetic and viscous boundary layer deserves special care.

Rotating magnetic waves in stably stratified layers

Chris Jones
University of Leeds

Abstract

Waves in a thin layer on a rotating sphere are studied. The effect of a toroidal magnetic field is considered, using the shallow water ideal MHD equations. The work is motivated by suggestions that there is a stably stratified layer below the Earth's core mantle boundary, and the existence of stable layers in stellar tachoclines. Magnetic instabilities can occur when the field is strong. Waves can be divided into magneto-inertial gravity waves, magneto-Kelvin waves, fast and slow magnetic Rossby waves. The properties of these waves will be discussed.

Can libration maintain Enceladus's ocean?

Rich Kerswell
University of Cambridge

Abstract

Current consensus is that Enceladus (the sixth largest moon of Saturn) has a global subsurface ocean of predominantly water. Given the cold temperatures in this part of the solar system (the surface temperature of Enceladus could be as low as -200C), it is an ongoing challenge to explain why this ocean doesn't freeze. I'll briefly discuss how to assess whether (pure) libration of the ice shell across the ocean and terrestial core could be important.

Decadal polar motion and electromagnetic core-mantle coupling: implications from geodynamo simulations

Weijia Kuang
NASA Goddard Space Flight Center

Abstract

It has long been observed that Earth's rotation axis orientation, called polar motion if defined in the terrestrial reference frame, varies on a wide range of time scales. It has also long been speculated that exchange of equatorial angular momentum between the Earth's fluid outer core and the solid mantle could be a major contributor to the observed decadal polar motion. However, none of the major coupling mechanisms, including the EM coupling across the core-mantle boundary (CMB), is found to be responsible for the angular momentum exchange.

The EM torques evaluated from geomagnetic observations are partial, and could be extremely underestimates of the true EM coupling torque because, except a fraction due to advection of the poloidal field by the core flow, other contributions from the outer core to the toroidal field in the mantle has been largely ignored. Using geodynamo simulations we have found that the missing parts can be orders of magnitude stronger than those retained in the previous studies, leading to a much stronger EM coupling torque which, as suggested by our simulation results, could potentially yield an order ~ 5 mas polar motion on time scales of 20 to 60 years. Should the EM coupling be responsible for the observed decadal polar motion, geodetic measurements could then be used to infer toroidal magnetic field and the convective flow beneath the CMB.

Cascade to large-scale vortices in spherical rotating convection

Yufeng Lin
University of Cambridge

Abstract

Large-scale coherent structures have been observed recently in numerical simulations of rapidly rotating convection in Cartesian boxes. However, similar structures have not yet been reported in the spherical geometry, which is more relevant to geophysical applications. In this talk, we will report numerical evidence of such large-scale coherent structures in a rapidly rotating whole sphere driven by internal heating. When the Rayleigh number is well above the critical value and a stress-free boundary condition is used for the velocity field, small-scale convective flows merge into large-scale structures, leading to a long-lived, axial-invariant cyclone around the rotation axis. We will discuss the formation of such large-scale cyclones and the heat transport associated with these large-scale structures.

Taylor state dynamos found by optimal control: axisymmetric examples

Phil Livermore
University of Leeds

Abstract

In 1963, Taylor promulgated an inertia-free and viscous-free model as the asymptotic limit of Earth's dynamo. In this theoretical limit, the velocity and the magnetic field organize themselves in a special manner such that the Lorentz torque acting on a geostrophic cylinder has to tend to zero as the inertial force and the viscous force tend to zero. We propose a new approach for solving this system based upon the concept of optimal control theory. In our method, the Lorentz torque is treated as the target function to be minimized at each time step and we seek the optimal geostrophic flow such that the Lorentz torque remains arbitrarily small at the future time step. We demonstrate the success of this approach on illustrative models, namely 2D axisymmetric systems driven by prescribed α- and $\alpha\omega$-effects. In this poster we will describe a number of dynamo solutions in the Taylor state.

Optimisation of Kinematic Dynamo in a sphere

Jiawen Luo
ETH Zürich

Abstract

In this study, we use a variational optimization approach to optimize laminar kinematic dynamos in a unit sphere and locate the enstrophy-based critical magnetic Reynolds number for dynamo action. Magnetic boundary condition is chosen to be either pseudo-vacuum or perfect-conductor boundaries. The spectra corresponding to two magnetic boundary conditions are identical by changing u into -u (Favier and Proctor 2013). A no-slip boundary for flow field gives a critical magnetic Reynolds number of 62.06, while a free-slip boundary reduces this number to 57.07. Optimal pairs (u, B_T) are found possessing certain rotation symmetries (anti-symmetries) and optimal flows share some common features. u localizes in a small region where it spirals up with very large velocity and vorticity, which is close to a Beltrami flow in the sense that u and curl u is nearly parallel in that region. Moreover, calculation of different helicities indicates that $\int A.u$ and $\int B.u$ might be important values that are expected to be small at the optima, with A the vector potential of B. A cheap way to achieve this is through symmetry. Comparisons with a recently obtained result by Chen Long using insulating magnetic boundary are made. We also discuss the energy requirement for dynamo action following (Proctor 2015).

Multiscale numerical simulations of magnetoconvection at low magnetic Prandtl and Rossby numbers

Stefano Maffei
University of Colorado, Boulder

Abstract

The dynamics of the Earth's outer core is characterized by low values of the Rossby, Ekman and magnetic Prandtl numbers. These values indicate the large spectra of temporal and spatial scales that need to be accounted for in realistic numerical simulations of the system. Current direct numerical simulation (DNS) are not capable of reaching this extreme regime, suggesting that a new class of models is required to account for the rich dynamics expected in the natural system. Here we present results from a quasi-geostrophic, multiscale model based on the scale separation implied by the low Rossby number typical of rapidly rotating systems. In particular, we investigate a plane layer geometry where convection is driven by an imposed temperature gradient and the hydrodynamic equations are modified by the presence of a large scale magnetic field. Analytical investigation shows that at values of thermal and magnetic Prandtl numbers relevant for liquid metals, the energetic requirements for the onset of convection is not significantly altered even in the presence of strong magnetic fields. Results from strongly forced nonlinear numerical simulations show the presence of an inverse cascade, typical of 2-D turbulence, when no or weak magnetic field is applied. For higher values of the magnetic field the inverse cascade is quenched.

Direction of the wave propagation and shock normal variation detection into earth magnetic ramp region in sunward earth radial distance 10.5 earth Mangetopouse transition region

Jivraj Pipaliya
University of Sheffield

Abstract

One of the key aspects of the in-situ measurements of collision less shocks is to identify direction of the wave propagation variation with shock normal in Quasi perpendicular shock front earth magnetic ramp transition region. It is argued that direction of the wave propagation and shock normal variation occurs at the earth magnetic ramp co-related to angle variation between shock normal and upstream magnetic field

A Possible Origin of the Earth's Dipole Magnetic Field

John Shebalin
George Mason University

Abstract

The Earth's quasi-steady dipole magnetic field may well be due to MHD turbulence within the outer core. Here, the theoretical and computational results that lead to this hypothesis will be discussed, and new numerical results will be presented. A comparison of IGRF spectra with spectra from new forced, dissipative Fourier method numerical simulations will be presented. This will require a discussion of the relationship between spherical harmonic degree and turbulence wavenumber, which are generally not equivalent. These results also include a demonstration that energetic, quasi-stationary, largest-scale modes exist and are due to intrinsic properties of MHD turbulence. These quasi-stationary Fourier modes are analogous to the dipole term in a spherical harmonic expansion.

Baroclinically-driven flows and dynamo action in rotating spherical fluid shells

Radostin Simitev
University of Glasgow

Abstract

The dynamics of stably stratified stellar radiative zones is of considerable interest due to the availability of increasingly detailed observations of Solar and stellar interiors. We reports non-axisymmetric and time-dependent simulations of flows of anelastic fluids driven by baroclinic torques in stably stratified rotating spherical shells - a system serving as an elemental model of a stellar radiative zone. With increasing baroclinicity a sequence of bifurcations from simpler to more complex flows is found in which some of the available symmetries of the problem are broken subsequently. The poloidal component of the flow grows relative to the dominant toroidal component with increasing baroclinicity. The possibility of magnetic field generation thus arises and this paper proceeds to provide some indications for self-sustained dynamo action in baroclinically-driven flows. We speculate that magnetic fields in stably stratified stellar interiors are thus not necessarily of fossil origin as it is often assumed.

The Equatorial Ekman Layer

Andrew Soward
Newcastle University

Abstract

The steady incompressible viscous flow in the wide gap between spheres rotating about a common axis at slightly different rates (small Ekman number E) has a long and celebrated history. The problem has particular application to the geodynamo and other planetary dynamos, where the moving electrically conducting fluid responsible for the dynamo is confined in such a geometry. A comprehensive asymptotic study, in the limit $E \ll 1$, was undertaken by Stewartson (J. Fluid Mech. 1966, vol. 26, pp. 131-144). In addition to the inner and outer boundary $E^{1/2}$ Ekman layers, he identified a set of nested shear layers on the inner sphere tangent cylinder: inside $E^{2/7}$, outside $E^{1/4}$. They embed an $E^{1/3}$ shear layer, which merges with the inner sphere Ekman layer to form the $E^{2/5}$ Equatorial Ekman layer of axial length $E^{1/5}$. We are unaware of any analytic solution of this $E^{2/5}$ layer. We present a numerical solution, which adopts non-local integral boundary condition to account for the far field behaviour as the $E^{2/5}$ and $E^{1/3}$ layers separate and become distinct. We compare our higher order extension of Stewartson's asymptotic similarity solution with our numerics.

Evolution of MHD waves in a rotating fluid

Binod Sreenivasan
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Abstract

Turbulence in the Earth's core is thought to be driven by blobs of light elements released from the inner core boundary. The long-time evolution of a flow disturbance subject to background rotation and a magnetic field provides some insight into the character of small-scale turbulence in the core. In this study, two regimes are analysed in the inviscid limit, that of strong rotation where the inertial wave frequency is much higher than the Alfvén wave frequency, and that of weak rotation where the Alfvén wave frequency is dominant. In either regime, the evolution consists of a damped wave-dominated phase followed by a diffusion-dominated phase. For strong rotation, the laws of energy decay in the damped wave phase are obtained by considering the decay of the fast and slow Magneto-Coriolis (MC) waves individually. The diffusion-dominated phase obeys the decay laws in the well-known quasi-static approximation. The wave–diffusion transition time scale indicates that the wave phase of decay is very long, so that small-scale turbulence in the core is characterised by perpetual damped wave motions. Interestingly, the induced magnetic field is far more efficient than the velocity in supporting slow MC waves. In the regime of weak rotation, the fast and slow MC wave solutions merge and tend to the non-dispersive damped Alfvén wave solution. Here the decay laws in non-rotating MHD turbulence are recovered. The present study suggests that a mean intensity of ∼10 mT or higher is plausible for the toroidal magnetic field within the Earth's core.

Dynamos, instabilities, inverse problems: Paul Roberts' legacy for experimental MHD

Frank Stefani
Helmholtz-Zentrum Dresden-Rossendorf

Abstract

Retracing Paul Roberts' footsteps, I survey the recent experimental activities related to dynamo action, magnetically triggered flow instabilities, Alfvén waves, and magnetic flow tomography. I'm certain he will be most pleased by those developments that have superseded some of the pessimistic prognoses made in his seminal 1967 book: "Since processes of self-excitation are out of the question..." (p. 172), is just a case in point...

An Asymptotic Model of Rapidly Rotating Convective Dynamos

Steven Tobias
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Abstract

Magnetic field generation in planets is modified by the presence of strong rotation. In such planets, the primary balance is controlled by the rotation rate and dissipative processes, with the small magnetic Prandtl number being key. Rotation and pressure always play an important role and magnetic field may enter into the leading order balance, though the relative importance of geostrophic motions to magnetostrophic motions is uncertain (and presumably scale-dependent). Here I shall present an asymptotic model of rotating convective dynamos and magnetoconvection where the leading order balance is that of geostrophy. The magnetic energy in such dynamos is asymptotically larger than the kinetic energy. I shall describe the derivation of these model, some numerical integrations and some possible generalisations.

Anisotropic particle diffusion in field-guided magnetohydrodynamic turbulence

Yue-Kin Tsang
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Abstract

Magnetohydrodynamic (MHD) turbulence with a background magnetic field is relevant to many astrophysical processes such as solar wind transport. We investigate how a mean guided-field alters the Lagrangian transport of tracer particles in MHD turbulence. We find that the mean-squared-displacement grows linearly with time, indicating a diffusive behavior. As the strength of the guided-field increases, the diffusion becomes anisotropic with larger diffusivity in the field-parallel direction. Interestingly, associated with such transition are changes in the behavior of the Lagrangian velocity correlation function. The Lagrangian velocity decorrelation time exhibits a power-law scaling with the root-mean-squared velocity. The scaling exponent shifts from -1 to -2 as anisotropic diffusion develops in the system, signalling a switching from the hydrodynamic-like regime to a MHD turbulence regime of interacting Alfven waves.

Liquid metal convection in a horizontal magnetic field

Tobias Vogt
Dresden

Abstract

Magnetohydrodynamic Rayleigh-Bénard convection was studied experimentally and numerically using a liquid metal inside a flat box with square horizontal cross section and aspect ratio five. The magnetic field in our experiments is applied in horizontal direction perpendicular to the temperature gradient. A sufficiently strong magnetic field causes a quasi-two-dimensional convection pattern in a way that the convection rolls are oriented along the magnetic field lines. We used variable field strength in this study in order to investigate the transition from a disordered to quasi-two-dimensional convection. We present systematic flow measurements that were performed by means of ultrasound Doppler velocimetry. We observed several different flow patterns depending on the balance between Lorentz force and buoyancy. The velocity measurements give an insight into the dynamics of the primary convection rolls, the secondary flow induced by Ekman pumping and reveal the existence of small vortices that develop around the convection rolls. The measurements were accompanied by direct numerical simulations in order to illustrate the time dependent, three dimensional velocity field. The overall agreement between experiment and numerical results is very good.

Advective core surface flows deduced from geomagnetic secular variation data

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Abstract

In 1965, Paul Roberts (with Scott) pointed out the ambiguity in deducing advecting core surface flows from the geomagnetic secular variation, and began discussions about ways to reduce the uncertainty. This seminal paper set the scene for much subsequent research into the subject, including further work on defining the ambiguity by Backus (1968) who also identified how to establish that the data are consistent with a purely advective. A number of authors subsequently have made assumptions that allow the ambiguity to be reduced, and provide methods to test for consistency with the assumption. This has provided information on the dynamical regimes of the core, and informed geodynamo investigations. Flow models have also been validated by comparing their predictions of decadal timescale changes in length of day with the observations. Here, we present core surface flow models covering the period from the start of the CHAMP satellite era to the present day, using data from the Swarm satellite constellation, and filling in the period between the two missions by geomagnetic observatory data. We use annual differences of monthly mean data to define the secular variation, either from observatories or an updated 'virtual observatories' (VO) method applied to satellite data. Our models share many of the features identified in other studies, such as the planetary gyre, and flow accelerations at the times of geomagnetic impulses or 'jerks'. The models fit the data to within their uncertainties, but the residuals are correlated, possibly reflecting incomplete removal of external fields.

Asymptotic theory for equatorially antisymmetric convection in rotating fluid spheres

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University of Exeter

Abstract

This paper is concerned with the classical problem of convective instabilities in rapidly rotating,self-gravitating, internally heated Boussinesq fluid spheres studied by P. H. Roberts (1968).We present a new asymptotic solution describing convection-driven torsional oscillation – whose flow velocity and pressure are fully analytical and in closed form.The asymptotic solution is in the form of equatorially anti-symmetric torsional oscillation, in quantitative agreement with the result of the numerical simulation, and physically preferred in a special range of small Prandtl number for rapidly rotating fluid spheres with the stress-free boundary condition.