[S7-P01] Magnetoconvection: Laboratory Experiments in Liquid Gallium

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Abstract

In this poster, we will present results to date of an ongoing suite of non-rotating magnetoconvection experiments, being carried out to further our understanding of the essential behaviors of liquid metal magneto-turbulence relevant to planetary core-like systems. These laboratory experiments are conducted using UCLA's RoMag device, in which we apply a vertical magnetic field to right cylindrical tanks filled with liquid gallium. Thus far, we have employed 20 cm high fluid layer in a tank with near 20 cm in diameter, corresponding to a diameter-to-height aspect ratio of Gamma = D / H = 1. Applied vertical magnetic fields have varied from Bz = 50 Gauss to 800 Gauss, corresponding to Chandrasekhar numbers (Q = Lorentz / Viscous) from 4E4 to 1E5. Using heat fluxes ranging from 30 W to nearly 3 kW has allowed us to survey Rayleigh numbers (Ra = Buoyancy / Diffusion) from 2E5 to 1E8. Our initial thermal field measurements show that the onset of convection occurs at Rayleigh numbers well below those predicted for magnetoconvection occurring in an infinite fluid layer. This likely signifies that magnetoconvection in our finite cylindrical tanks onsets via stationary wall-attached modes [1][2]. Further, a novel bifurcation is observed in the vicinity of unity interaction parameter in which the thermal signals indicate a processing structure develops in the fluid. These end-member non-rotating magneto-turbulence observations are crucial for the evolving interpretation of the rotating magneto-turbulence that exists in planets and stars.

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*Speaker

[S7-P02] Simultaneous measurements of axial velocity and heat transfer in rapidly rotating turbulent convection

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Abstract

The 'NoMag' laboratory device is designed to simulate a local, polar parcel of planetary core convecting fluid under the influence of axial rotation and buoyancy forcing. As such, a cylindrical geometry is constructed with a fixed diameter of D 60 cm and heights ranging between 5 cm < H < 185 cm. Using this device, we explore the properties of rotating convection in water (Pr 7), with Ekman numbers ranging between E 3×10ˆ−8 (i.e. 60 rpm, H 185 cm) to E 10ˆ−3 (i.e. 1.5 rpm, H 5 cm) and Rayleigh numbers between Ra 10ˆ5 (i.e. 50 watts, H5 cm) to Ra 10ˆ13 (i.e. 3000 watts, H185 cm). We utilize laser doppler velocimetry (LDV) to obtain point measurements of bulk axial velocity at z H/3, r = 5R/6, resulting in measured Reynolds numbers ranging between 10ˆ2 < Re < 5×10ˆ4. We simultaneously collect temperature time series at the fluid boundaries and at multiple locations within the fluid bulk in order to characterize heat transfer processes. We will present recent experimental results with aspect ratios = D/H 3, 1.5, 0.75 (H 20, 40, 80 cm) that test heat transfer and convective velocity field scaling predictions relevant to rapidly rotating systems. Finally, we will provide evidence that our laboratory data contain negligible effects of centrifugation, except in our most rapidly rotating 0.75 cases.

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[S7-P03] A laboratory approach to characterizing heat transfer in extreme geostrophic convection

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Abstract

Like many geophysical and astrophysical systems, flow in the outer core of the Earth is driven by buoyant instabilities and heavily influenced by rotation. Rotating Rayleigh-Bénard convection provides a canonical framework for understanding such flows, particularly in relation to the tangent cylinder region of the core. However, the most geophysically-relevant regimes of rotating convection cannot be fully characterized within the limits of present-day laboratory experiments and numerical simulations. Here we present a suite of heat transfer results from TROCONVEX, a new 4-meter-high rotating convection device designed to access ranges of the governing parameters an order of magnitude beyond previously achievable values. Our new thermal measurements give insight into the underlying flow behaviors and allow us to disentangle disparate flow regimes from one another. This paves the way for determining the physical mechanisms through which regime transitions occur, as well as the relationship of these regimes with geophysical phenomena.

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[S7-P04] Effects of bottom topography on rotating fluids

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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 $(\lambda) are investigated, ranging from cases where \lambda i$ $synchronization time, the so called spin-up time, with a minimum at a specific length scale of the bottom topography. We obser$

*Speaker

[S7-P05] Modal acoustic velocimetry in a rotating sphere: preliminary results

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Abstract

In a spherical cavity, the pressure field has a discrete set of solutions, separated in frequencies, called eigenmodes. In a perfect sphere, these modes are degenerate in the azimuthal direction, but in presence of internal flows, this degeneracy can be lifted causing a splitting of modes. In this study we use splittings of acoustic eigenmodes as a measure of internal flows in a laboratory experiment. The experiment setup consists of a 20 cm-radius brass shell filled with air, which can spin at up to 15Hz.

By solving the inverse problem we can obtain the fluid motions inside the experiment. To test this new experimental measurement method, we apply it on different cases of azimuthal flows. First, on solid bady rotation of the set-up, in which we can retrieve the effect of the Coriolis force on the acoustic modes, as predicted by theory. Then on spin-up and spin-down induced flows, where we can retrieve the differential cylindrical anglular velocity and its temporal variation. We also show preliminary results for azimuthal libration of the fluid. In the future, we plan to use this technique to measure the geometry and the amplitude of zonal flows which appear in a rapidly rotating thermal convection experiment, with the perspective to better understand internal flows in giant planets and planetary cores.

*Speaker

[S7-P06] Turbulence in the spherical Couette system

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Abstract

The spherical Couette system consists of two concentric differentially rotating spheres. We study a regime of the system where the Coriolis force dominates the dynamics (Ekman number, E less than or equal to 1e-4) and the differential rotation is 'negative' meaning the inner sphere rotates slower or in a direction opposite to that of the outer sphere. As the differential rotation magnitude is increased, the system traverses through different hydrodynamic regimes - starting from a Stewartson Layer instability, followed by an m=1 instability, followed by onset of global inertial modes and finally a transition to turbulence. In this study, we simulate this system and compare with experiments performed in Cottbus, Germany as well as in Maryland, USA. Our simulations reproduce the major features observed in the experiments in Cottbus and successfully predict observations in Maryland. We focus on the turbulent regime where the temporal spectrum reveals inertial wave turbulence and the spatial spectra show a gradual increase of transport to small scales. We further study change in force balances and compare the boundary layer structure with a classical Prandtl-Blasius scaling.

*Speaker

[S7-P07] Experimental study of rotating convection subject to laterally varying boundary heat flux

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Abstract

The presence of lateral variations in heat flux across the core-mantle boundary (CMB) modies the structure of convection in the core, with regions of relatively high heat flux promoting convection beneath them. It is plausible that this concentration of convection gives rise to the near-stationary high-latitude flux lobes in the present day geomagnetic field. Here, we present an experimental study that examines the role of laterally varying boundary heat flux on rapidly rotating convection. The apparatus consists of a cylindrical annulus rotating about its central axis. The maximum centrifugal acceleration produced in the set-up is approximately one order of magnitude higher than Earth's gravity. Isothermal conditions are set at the inner boundary and an azimuthally varying heat flux is applied at the outer boundary on which the Rayleigh number (Ra) is based. Experiments are performed with water at an Ekman number E = 1.8 x 10ˆ(-6). The convection pattern is determined by the ratio of the peak-to-peak heat flux variation to the mean value of heat flux, q*. For moderate values of q* (< 1), the vortices are strongly localised in the azimuthal direction for convection not far from onset (Ra _˜ Rac). For q* _˜ 2, a coherent cyclone–anticyclone vortex pair is formed for a wide range of Rayleigh numbers (Ra _˜ 10Ra_c) until convection is homogenized in the annulus at Ra/Ra_c _˜ 50. Furthermore, convection sets in at much lower values for the total power input with inhomogeneous heating compared with the case of homogeneous boundary heat flux. Our study suggests that convection at preferred longitudes can occur in the Earth's core even in highly supercritical convection, provided the lateral heat flux variation in the lower mantle is at least twice the mean CMB heat flux.

*Speaker

[S7-P08] Experimental study of the Effect of Boundary Topography on the Flow forced by Libration in Longitude in a Rotating Cylinder

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Abstract

Abstract
Forced librations in longitude are oscillatory modulations of a planet's or moon's rotation frequency resulting from gravitational interaction with orbital partners. This mechanical forcing has a strong impact on the dynamics of planetary fluids like subsurface oceans or liquid cores. A topography at the fluid boundary is expected to modify the fluid response to the forcing, but its exact influence is poorly understood. This study aims at providing part of the answer by analysing the effect of a basal topography on the onset of instabilities driven by the longitudinal libration. To this purpose, the flow driven by librations in longitude in a rapidly rotating cylinder is studied experimentally using Particle Image Velocimetry (PIV). In the first place, we consider a cylinder with flat end walls in order to allow a direct comparison in our experimental setup and with previous studies (Noir et al, 2010, Cebron et al 2012a,b, Calkins et al 2010). We show that 4 regimes characterise the dynamics in the bulk. At low Rossby number the response is laminar with a monochromatic spectrum. By increasing Rossby number we observe a first transition as the onset of a parametric resonance. At higher Rossby number strong low-frequency inertial modes form in addition to the parametric instabilities. Finally, at large enough amplitude of libration, strong non-linearities develop in the system and the aforementioned triadic resonances are no longer observed. In the second part we present preliminary results obtained with a sinusoidal topography with a wavenumber m=5.

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*Speaker

[S7-P09] Compressible Convection Experiment using Xenon Gas in a Centrifuge

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Abstract

Thermal convection is an important mechanism in a lot of geophysical and astophysical systems in which compressibility is important due to large variations of pressure caused by large scales structures. To study these kind of systems, we usually use the anelastic approximation. This approximation consist in studying convection as fluctuations around an isentropic state. The hydrostatic pressure gradient and the isentropic hypothesis imply the existence of a temperature gradient, called the adiabatic gradient, in the radial direction.

The anelastic approximation has been applied in theoretical and numerical models. We present here an experiment especially designed to study compressible convection in the lab. The parameters of the experiment have been optimized for having significant compressible convection effects. We use xenon gaz placed in a centrifuge to reach a dissipation number close to Earth's outer core value.

We will present our results for different heating fluxes and rotation rates. We successfully observe an adiabatic gradient of 3K/cm in the cell. We show that the heat transfert follows a 1/3 power law between the Nusselt number and the Rayleigh number. Studies of pressure and temperature fluctuations lead us to think that the convection takes place under the form of a single roll in the cell for high heating fluxes. Moreover, these fluctuations show that the flow is geostrophic due to the high rotation speed.

*Speaker

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[S7-P10] Torsional Alfvén waves in a dipolar magnetic field: experiments and simulations

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Abstract

Eight years after the discovery of torsional Alfvén waves in the Earth's core (Gillet et al, 2010), we report on the first experimental study of such waves.
In our DTS experiment, some 40 liters of liquid sodium are contained between a r_o = 210 mm-radius stainless steel outer shell, and a r_i = 74 mm-radius copper inner sphere. Both spherical boundaries can rotate independently around a common vertical axis. The inner sphere shells a strong permanent magnet, which produces a nearly dipolar magnetic field whose intensity falls from 175 mT at r_i to 8 mT at r_o in the equatorial plane.

We excite Alfvén waves in the liquid sodium by applying a sudden jerk of the inner sphere. To study the effect of global rotation, which leads to the formation of geostrophic torsional Alfvén waves, we spin the experiment at rotation rates f_o = f_i up to 15 Hz.

We measure the propagation of the wave with magnetometers inside a sleeve. It takes only a few hundredths of a second for the wave to travel from the inner sphere to the outer sphere. In order to decipher the behavior of the waves, we perform numerical simulations with the XSHELLS software, using the same parameters as in the experiment, except for the fluid viscosity. We identify a subtle difference in the magnetic field records that differentiates Alfvén waves from torsional Alfvén waves. We also document differences in the surface electrical potentials linked to the geostrophic nature of fluid velocities when global rotation is present.
Magnetic diffusion plays a major role in our DTS experiment, and the Alfvén waves we propagate are far from ideal, but they reveal interesting properties of fundamental MHD phenomena.

*Speaker

[S7-P11] Experimental Investigation of Core Crystallization in Small Terrestrial Bodies

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Abstract

Core crystallization is a crucial ingredient in the evolution of terrestrial bodies and is controlled primarily by chemistry and temperature. Transport properties, such as electrical resistivity, are a relevant probe of core crystallization processes, as variations in mass and heat transport in the cooling fluid likely impact the convective and diffusive mechanisms that govern the structure and dynamics of the core and might contribute to generate a magnetic field.
Electrical experiments are reported on core analogues in the Fe–S system and on FeSi2 from 3.2 to 8 GPa and up to 1850C using the multi-anvil apparatus. Electrical resistivity was measured using the four-electrode method. For all samples, resistivity increases with increasing temperature. The higher the S content, the higher the resistivity and the resistivity increase upon melting. The resistivity of FeS and FeSi2 at 4.5 GPa is comparable at temperature below the melting temperature, whereas FeS becomes more resistive than FeSi2 by a factor of two upon melting, suggesting a stronger influence of S than Si on liquid resistivity.

Electrical results are used to develop crystallization-resistivity paths considering both equilibrium and fractional crystallization in the Fe–S system. At 4.5 GPa, equilibrium crystallization, as expected locally in thin snow zones during top-down core crystallization, presents electrical resistivity variations from about 300 to 190 microhm-cm for a core analogue made of Fe-5 wt.%S, depending on temperature. Fractional crystallization, which is relevant to core-scale cooling, leads to more important electrical resistivity variations, depending on S distribution across the core, temperature, and pressure. Estimates of the lower bound of thermal resistivity are calculated using the Wiedemann–Franz law. Comparison with previous works indicates that the thermal conductivity of a metallic core in small terrestrial bodies is more sensitive to the abundance of alloying agents than that of the Earth's core.
Application to Ganymede using core adiabat estimates from previous studies suggests important thermal resistivity variations with depth during cooling, with a lower bound value at the top of the core that can be as low as 3 W/mK. It is speculated that the generation and sustainability of a magnetic field in small terrestrial bodies might be favored in light element-depleted cores. This experimental investigation underlines the importance of crystallization-induced distribution of alloying agents across the core on the transport properties of cooling terrestrial bodies.

*Speaker

[S7-P12] Features of the fall of an iron diapir through a magma ocean and their consequences on chemical and thermal exchanges

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Abstract

The investigation of Earth's early history, from the condensation of the dust in the solar nebula to the last impact that probably formed the moon, faces the challenge of having few data while being confronted to a multi-variate problem. Consequently, some events that are thought to better explain the present state of our planet still have their parameters very badly constrained. This is for instance the case for giant impacts between differentiated Mars-size planetesimals. Indeed, the merging of the two iron cores that would immediately follow the impact can be seen as a late mixing between the iron of the core and the silicate of the mantle since both were likely molten at that time. The heat and elements exchanged during that process and their repartition after re-equilibration remain open questions.

We run a laboratory experiment with analog fluids with the aim at providing a better understanding of this process for the interpretation of geochemical data. This allowed us to reproduce flows similar to the release of a large amount of liquid iron at the top of a magma ocean and its subsequent fall. By filming the fall of a liquid metal through a viscous fluid over a large depth, we were able to isolate some of the finer features of the flow that should be included in planet building models.

Our measures suggest that prior to the breakup of the liquid metal, the fall of the liquid metal is more similar to the one of a toroidal vortex than previously envisioned (Deguen et al 2011, Deguen et al 2013, Wacheul and Le Bars 2014). The hypotheses concerning the modalities of the diffusive transfer between the two phases are revised accordingly and a length scale of equilibration for this part of the fall is provided. The distribution of sizes of droplets as a function of the parameters of the problem allows improving the length scale of equilibration that should be used after a cloud of droplets has been formed. In addition, the persistence of a toroidal vortex well after the settling of the metal droplets is discussed in the broad context of the mixing magma ocean.

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