Sequential assimilation of the Earth's magnetic field

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Abstract

The magnetic field of the Earth is composed of many sources. Isolating them from direct measurements at the Earth's surface or at the altitude of low orbiting satellites is a challenging task. Nevertheless, advantage can be taken from the distinct dynamics of these sources. Whereas internal fields such as the core field or the lithospheric field are either evolving slowly (the core field) or are almost static (the lithospheric field), external fields such as the ionospheric field, the magnetospheric field or the fields the latter induce within the upper mantle, the crust and the ocean, vary extremely rapidly in time. In general, magnetic field models deriving from ground based observatory and satellite data, are a priori enforcing these specific temporal properties, but they often neglect the crucial information coming from the particular morphology and spatial correlations that each field is exhibiting. Yet, combining spatial and temporal constraints within an inversion framework can improve the separation of the different contributions to the observed magnetic field. Nevertheless, a high model complexity necessarily implies important computational needs. Moreover, to obtain an optimal separation, every overlapping field have to be simultaneously considered, and this, down to their smallest significant timescales, which in turn leads to a further escalation in numerical costs. This is why we developed a sequential data assimilation algorithm in order to combine sophisticated spatio-temporal models for the different magnetic field sources and measurements of the Earth's magnetic field at high temporal resolution. This method is not only attractive because it drastically reduces the needs in computational power, it also gives access to uncertainties estimates and predictions of future states.

*Speaker

Chemical trends in ocean islands explained by plume–slab interaction

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Abstract

Earth's surface shows many features whose genesis can only be understood through their connection with processes in Earth's deep interior. Recent studies indicate that spatial geochemical patterns at oceanic islands correspond to structures in the lowermost mantle inferred from seismic tomographic models. This suggests that hot, buoyant upwellings can carry chemical heterogeneities from the deep lower mantle towards the surface, providing a window to the composition of the lowermost mantle. The exact nature of this link between surface and deep Earth remains debated and poorly understood. Using computational models, we show that subducted slabs interacting with dense thermochemical piles can trigger the ascent of hot plumes that inherit chemical gradients present in the lowermost mantle. We identify two key factors controlling this process: (i) If slabs induce strong lower mantle flow towards the edges of these piles where plumes rise, the pile-facing side of the plume preferentially samples material originating from the pile and bilaterally asymmetric chemical zoning develops. (ii) The composition of the melt produced reflects this bilateral zoning if the overlying plate moves roughly perpendicular to the chemical gradient in the plume conduit. Our results explain some of the observed geochemical trends of oceanic islands and provide insights into how these trends may originate.

*Speaker

Lower mantle structure and dynamics: constraints from observations and models

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Abstract

To date, seismic tomography models, which are mapping lateral changes in seismic velocities, provide the best information on the structure of the Earth's mantle. Global models built during the past two decades have reached a consensus on the large scale structure. The strongest heterogeneities are found in the topmost 300-400 km of the mantle, where they correlate with surface tectonics, and in its lowermost 400-500 km, where the dominant structures are two large low shear-wave velocity provinces (LLSVPs) located beneath Africa and the Pacific. Additional important information on mantle structure can be obtained through experimental and numerical simulations of convection, modelling mantle dynamics. Depending on input parameters, simulations predict possible thermo-chemical structures that can be tested against geophysical observable, in particular seismic tomography maps.
Because changes in seismic velocity anomalies alone cannot simultaneously resolve the thermal and compositional contributions from which they originate, the interpretation of tomographic maps remains ambiguous. A perfect illustration of this problem is the discussion on the nature of LLSVPs. These structures have been observed by many different seismological studies based on different datasets (Ritsema et al., 2011; Lekić et al., 2012), and thus appear as robust features. By contrast, their nature, purely thermal or thermo-chemical, is still debated (Garnero et al., 2016). Dynamically, LLSVPs may be associated either with clusters of purely thermal plumes, or with piles of chemically differentiated, hotter than average, material. To reproduce patterns similar to LLSVPs, the plume clusters hypothesis requires a substantial filtering, accounting for the fact that global tomography has limited resolution and that seismic data contains errors and bias (*e.g.*, Davies et al., 2012). Importantly, numerical simulations showed that reservoirs of dense material, modelling LLSVPs, can be maintained for long periods of time provided that the chemical density contrast between these reservoirs and the surrounding mantle is large enough, typically around 1.5-2.0 % (*e.g.*, Li et al., 2015). While several observations, including the anti-correlation between shear-wave and bulk sound seismic velocities (Ishii and Tromp, 1999; Masters et al., 2000; Trampert et al., 2004), strongly favor a thermo-chemical origin, other studies pointed out that these observations may result from complex wave-propagation effects through purely thermal structures (Schuberth et al., 2012), or be explained by the presence of post-perovskite around them (Hutko et al., 2008; Davies et al., 2012). Therefore, discriminating between purely thermal and thermo-chemical scenarios of deep mantle requires constraints independent from seismic velocity structure, *i.e.* from travel time data alone. Here, I'm discussing possible constraints that may help discriminating between purely thermal and thermo-chemical hypothesis. These includes seismic normal modes, tidal tomography, core-mantle boundary topography, variations in the length of the day, seismic attenuation, and electrical conductivity.

*Speaker

Seismic normal modes allows mapping lateral density variations, but different studies arrived to opposite conclusions. Several studies pointed out that density changes are de-correlated or negatively correlated with shear-wave velocity anomalies, globally supporting the thermo-chemical hypothesis (Ishii and Tromp, 1999; Trampert et al., 2004; Mosca et al., 2012; Moulik and Ekstr´om, 2016). Stoneley mode measurements, by contrast, concluded that LLSVPs may be less dense than surrounding mantle (Koelemeijer et al, 2017). It should be kept in mind that the mode splitting data used in these studies are based on the self-coupling approximation, which might bias the inference of density structure (Yang et al., 2015). The tidal tomography developed by Lau et al. (2017) is also based on normal modes summation, but it uses a full coupling method instead of self-coupling. Applied to recent catalogues of solid Earth's tide measured from GPS data, this method report density excess by ˜ 0.5 % in LLSVPs. This value represents an average over a 400 km thick layer, and due to lack of radial resolution it is not possible to determine whether it results from anomalies evenly spread throughout this layer, or from denser anomalies located closer to the core-mantle boundary (CMB).

Other series of observations point out that LLSVPs may have remained stable during the past 300 Myr, and potentially over much longer periods of time. These arguments include the small amplitude of the true polar wander, which exclude major mass redistribution at the bottom of the mantle (Dziewonski et al., 2010); the reconstruction of the geographical locations of Large Igneous Provinces, which mostly fit along the edges of LLSVPs or within them; and mantle flow patterns inferred from tectonic plate motions reconstruction, which indicate that upwellings beneath Africa and the Pacific have been stable around these locations during at least the past 250 Myr (Conrad et al., 2013). Dynamically, the long-term stability of LLSVPs are better explained by thermo-chemical models of convection than by clusters of purely thermal plumes.

Variations in the Earth rotation may bring further important information. A well-known, but still unexplained variation is the 6-year periodic changes in the length of the day. Recently, it has been shown that these variations may be explained by gravitational coupling between the inner core and the lowermost mantle, which would imply mass excess in regions overlapping LLSVPs (Chao, 2017; Ding and Chao, 2018).

CMB topography is difficult to measure, in particular because it trade offs with seismic structures of the deep mantle, and available global maps strongly differ both in pattern and amplitude. However, recent numerical simulations of thermal and thermo-chemical convection (Deschamps et al., 2018) suggest that the long wavelengths of CMB dynamic topography, provided they can be measured, provide a simple test to infer the nature of LLSVPs. In these models, piles of dense material induce shallow depression of the CMB, a pattern that is consistent with the CMB topography map inferred by Tanaka (2010) from P4KP - PcP differential travel times.

Finally, two other promising observables are long-period electromagnetic C-responses, and seismic attenuation. Electromagnetic C-responses are related to the distribution of electrical conductivity in the deep mantle, which, in turn, depends on temperature and on the exact composition of the mantle aggregate. Different thermo-chemical structures lead to clearly different C-responses (Deschamps et al., 2016). However, building accurate C-responses at long periods ($>$ 1 year) requires series of geomagnetic data over longer time intervals, typically several decades. Seismic attenuation, measured with the quality factor Q, can be measured from seismic waveform inversion. While its measurement may be biased by focusing effects (*e.g.*, Cottaar and Romanowicz, 2012), and despite remaining uncertainties in its modelling, Q certainly carries key information on temperature. Combined with shear-velocity models, variations in Q may be used to infer the thermo-chemical structure of the deep mantle (Konishi et al., 2017).

Constraining mantle anisotropy with seismology and geodynamics

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Abstract

Seismic anisotropy provides key information to map the trajectories of mantle flow and understand the evolution of our planet. While the presence of anisotropy in the uppermost mantle is well-established, the existence and nature of anisotropy in the transition zone and lower mantle are still debated. Here we review recent developments in the global seismic imaging and interpretation of radially anisotropic mantle structure. We show that it is highly beneficial to invert simultaneously for mantle and crustal structure using multiple seismic datasets. Moreover, we show that comparisons between anisotropy tomography and combined micro- and macro-flow geodynamic simulations help constrain the patterns of mantle convection. We present new results highlighting the ubiquitous presence of anisotropy in the uppermost lower mantle beneath subduction zones. Whereas above the 660-km seismic discontinuity slabs are associated with faster SV anomalies up to _˜3 %, in the lower mantle faster SH anomalies of _˜2 % persist near slabs down to _˜1,000-1,200 km. These observations are consistent with 3-D numerical models of deformation from subducting slabs and the associated lattice preferred orientation of bridgmanite produced in the dislocation creep regime in areas subjected to high stresses.

*Speaker

Stories from the depths of small planets and large moons

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Abstract

The solar system is filled with worlds largely unlike the Earth yet still governed by the same sets of processes that have shaped the Earth. The planets and moons smaller than our home planet display a variety of internal structures and evolutionary paths. In turn, each of these bodies provides a different perspective on both the influence of specific process and the arc of planetary evolution. Mercury is a large, ˜2000 km radius metallic core with a thin silicate outer shell while the Moon is a sharp contrast with a much deeper mantle and a small metallic core. In the outer solar system, Jupiter's moons Ganymede and Europa have layers of solid and liquid water that overlay rock mantles and metallic cores (though Europa's has yet to be definitively identified). While Mercury and Ganymede are of similar size and both have actively generated magnetic fields, the latter has nearly 900 km of water and ice atop its silicate mantle, providing a rather different boundary condition for the icy moon's mantle. Europa on the other hand is almost the size of the Moon and neither has a present day magnetic field. Moreover, rather than an ancient, heavily impacted surface Europa has a seafloor overlain by an ocean that imparts as much pressure as a 20 km deep ocean on Earth. Other than the Moon (and soon Mars via the NASA InSight mission) the internal structures of small bodies constrained solely by gravity and rotational observations supplemented in some cases by magnetic field data indicative of electrically conductive layers at depth. However, understanding of the deep interiors of small bodies is substantially aided by the fact that relevant materials can be readily studied in laboratory experiments due to the modest pressures in the interiors (e.g., central pressures of < 40 GPa). We will review several ways in which planetary bodies beyond Earth, particularly the smaller ones, are informing understanding of how planets evolve. An emphasis will be on our knowledge of planetary cores and how they operate – often quite differently from the traditional view of Earth's core.

*Speaker
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Life of the Core-Mantle Boundary

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Abstract

Earth's core-mantle boundary (CMB) pre-dates the Moon, and is the oldest persistent feature inside our planet, having materialized during proto-Earth's growth to embryo-size within _˜1Myr of the formation of the solar system. During the subsequent 4,566 million years of solar system evolution the CMB has seen quite a lot, starting with an eventful youth that included further accretion and core growth, violent episodes such as likely occurred during lunar formation, probable extensive melting and fractionation and mixing and unmixing, and other poorly known episodes, before settling into a more gentle lifestyle that moved at the sluggish speed of mantle convection. During most of its life time the CMB has been persistently shaped and deformed by relatively cold deep mantle convective flows, cooling the CMB region and setting up the conditions for convection in the underlying core. The CMB has facilitated the conveyance an unknown amount and kind of matter between the core and mantle, and may have witnessed several tempestuous geological episodes that strongly influenced Earth's surface environment. What does the CMB remember of this storied past? What can it tell us, and what questions should we ask it? In this review talk I will present a variety of views of the CMB region and examine how ideas regarding individual features are connected by a broad web of inter-relations with important threads that extend back to our planet's infancy.

*Speaker

Mantle dynamics following supercontinent formation: subduction, LLSVPs, and the formation of plumes

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Abstract

The Large Low Shear Velocity Provinces (LLSVPs) below Africa and the Pacific may be evidence of compositionally dense and chemically distinct material deep in the Earth's mantle, based on data from geochemistry, mineral physics, and seismology. The paleo-position of mantle upwellings deduced from large igneous provinces has previously been attributed to plume generation zones at the edges of these LLSVPs. However, the genesis of the upwellings, as well as the geodynamic nature of LLSVPs, are not well understood. In this study, we implement plate reconstruction histories in 3D global numerical models of mantle convection to explore the role of subduction and thermo-chemical piles on the position of upwellings following supercontinent formation. Furthermore, we identify areas of uncertainty with the numerical setup and plate reconstruction histories through comparison with mantle structure vote maps and present-day hot spot positions. Our models can produce appropriate plume position and thermo-chemical pile location (LLSVP) for the African hemisphere. However, in the Pacific hemisphere our models do not resemble present-day geodynamics. After vote map analysis and comparison with previous geodynamic studies, we propose that paleo-subduction history in the Pacific, in particular in the north, may require some further work. Alternative plate reconstructions are implemented into the numerical models and analysed with respect to their impact on mantle dynamics. In addition, it is the plate tectonic process of oceanic subduction that has the strongest influence on plume positioning in our models, rather than the pre-existing thermo-chemical structures within the deep mantle.

*Speaker

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Core composition?-Constraints from melting phase relations in binary and ternary iron alloy systems

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Abstract

The Earth's core composition has long been enigmatic but has profound implications for the Earth accretion and core formation processes as well as for the current state of the core. Recent diamond-anvil cell (DAC) experiments combined with electron microprobe analyses on recovered samples as well as synchrotron X-ray observations have revealed liquidus phase relations in iron–light-element systems to core pressures. Such liquidus phase relations, in particular eutectic liquid compositions are of great importance to constrain the present-day core composition by simply considering that the solid inner core is more dense than the liquid outer core.Such DAC experiments have become possible in large part because of technical developments involving a focused ion beam (FIB) apparatus. Interestingly, the liquidus phase relation in a ternary iron alloy system is in some cases very different from those in relevant binary systems; for example, SiO2exhibits a wide liquidus field in Fe–Si–O, suggesting that the liquid core originally enriched in both Si and O has evolved into a composition including either one of Si or O as a consequence of SiO2crystallization(Hirose et al., 2017). Such mutual exclusivity can be key to narrowing down the possible range of core composition. I will argue the chemical composition of the present-day outer core, on the basis of the liquidus phase relations and the eutectic liquid compositions in both binary (Fe–Si, Ozawa et al., 2016;Fe–S, Mori et al., 2017; Fe–O, Morard et al., 2017; Fe–C, Mashino et al., submitted) and ternary systems (Fe–Si–O, Hirose et al., 2017; Fe–Si–S, Tateno et al., 2018;Fe–S–O, and Fe–C–H).

*Speaker
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Dynamics and long term evolution of the deep mantle

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Abstract

Over the years, seismological evidence for lateral variations of composition in the deep mantle have accumulated: Large low velocity province (LLVPs), with uncorrelated P and S velocity variations, sharp edges to the LLVPs, patchy existence of ultra low velocity zones (ULVZs). These structures are the result of about 4.5 billion years of evolution and ideas about their origin will be discussed in this presentation. Variations of composition are formed by fractional melting and freezing and are reduced in scale by convective stirring. One place where fractional melting is known to produce compositional heterogeneities is near surface volcanism. Recycling of oceanic crust to the deep mantle at subduction zones has therefore been advocated for decades as a major source of compositional heterogeneities in the mantle. High-pressure transformations of crustal minerals can make them denser than the average mantle which can lead to their accumulation at the bottom of the mantle over time. Alternatively, it has been proposed that an initially flat compositional interface in the mantle can lead to the present situation by progressive mixing across the interface aided by convection in the two layers. Such an initial stratification can result from the overturn following upward fractional crystallisation of a magma ocean but overturning of the solid mantle is likely to happen during its cristallisation. Compositional heterogeneities can also result from fractional crystallisation of a basal magma ocean which produces solids that get denser with time and can stabilise against entrainment by convection. The existence of a basal magma ocean allows the matter to flow through the boundary by phase change which completely change the dynamics of mantle convection. For example, this leads to suppression of hot plumes which suggests a radical change of mantle dynamics after complete crystallisation of the basal magma ocean and opens perspectives to test this hypothesis.

*Speaker

Combining seismic observations and geodynamical models for exploring the Earth's inner core

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Abstract

A complex inner core structure has been well established from seismic studies, showing radial and lateral heterogeneities at various length scales. The major two seismic features are east-west hemispheres in velocity and attenuation, and complicated anisotropy, which may be oriented north-south, may be hemispherical, and may vary with depth. Yet, no geodynamic model is able to explain all the features observed. One of the main limits for this is the lack of tools to compare seismic observations and numerical models successfully.

I will present here a new Python tool called GrowYourIC to compare models of uppermost inner core structure seen as if sampled by PKIKP data sets. Properties of geodynamical models of the inner core are calculated along seismic ray-paths, for random or user-specified data sets. We tested kinematic models which simulate lateral translation, super rotation, and differential growth. Fast and slow translations are both able to generate a pattern of east-west asymmetry. The existence of a previously-proposed depth dependence of the boundary between the two hemispheres could be used to distinguish between fast and slow translation, if confirmed by additional studies.

Comparing real and ideal data sets, I will discuss some of the published models and how much they can be constrained by the seismic observations, with a particular interest for the resolution capabilities and limitations of the sparse existing seismic coverage. I will also present recent updates, which include anisotropy and additional flow models.

*Speaker

Earth's core formation in the lab

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Abstract

Understanding the formation of Earth's core is key for predicting its initial temperature and composition, and therefore its long-term evolution. Much of Earth's metallic core was delivered during high-energy impacts between planetary embryos. After each impact, the core of the impactor migrated through the mantle and merged with Earth's core. Geochemical observations constrain the timing and physical conditions of these impacts. However, to interpret these data, we must know the degree of mixing and chemical equilibration between metal and silicates. Recent fluid dynamical models estimate equilibration following an impact, but they entirely neglect the inertia of the impactor. We present novel laboratory experiments on metal-silicate mixing by planetary collisions. Our experiments replicate the cratering process observed in impact simulations. Unlike simulations, experiments produce small-scales and turbulent mixing. We obtain scaling laws for mixing as a function of the impact velocity and the impactor size. Applied to core formation, these scalings predict up to four times more equilibration than those that neglect the impactor inertia. We predict full metal-silicate equilibration for impactors much smaller than the Earth, but partial equilibration for giant impacts.

*Speaker

Tidal Tomography: What an often-neglected phenomenon known as Earth tides can tell us about buoyancy in the deepest part of the mantle.

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Abstract

Earth's mantle is a key component of the Earth system: its circulation drives plate tectonics, the long-term recycling of Earth's volatiles, and as such, holds fundamental implications for the Earth's surface environment. In order to understand this evolution, a key parameter of the mantle must be known, namely its buoyancy. In this talk, I will discuss how Earth's body tide can provide fresh and independent constraints on deep mantle buoyancy through a newly developed technique called *Tidal Tomography.* This comes at a time when other interesting and exciting data sets sensitive to deep mantle buoyancy, e.g., Stoneley modes, have been brought to bear, and we will explore our conclusions in the context of other recent finds. In particular, we will focus on two regions of the deep mantle known as the Large Low Shear Velocity Provinces (LLSVPs), the buoyancy of which has attracted much debate over the past few decades. Using a global GPS data set of high precision measurements of the Earth's body tide, we perform a tomographic inversion to constrain the integrated buoyancy of these LLSVPs at the base of the mantle. As a consequence of the long-wavelength and low frequency nature of the Earth's body tide, these observations are particularly sensitivity to LLSVP buoyancy. Using a probabilistic approach we find that the data are best fit when the bottom two thirds (_˜700 km) of the LLSVPs have an integrated excess density of _˜0.60%.

*Speaker

Experimental fluid dynamics for planetary cores

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Abstract

Understanding the flows in the liquid core of telluric planets, from their formation to their current dynamics, is a tremendous interdisciplinary challenge. Beyond the challenge in fundamental fluid dynamics to understand these extraordinary flows involving turbulence, rotation and buoyancy at typical scales well beyond our day-to-day experience, a global knowledge of the involved processes is fundamental to a better understanding of the initial state of planets, of their thermal and orbital evolution, and of magnetic field generation.
It is obviously out of reach for any model to include simultaneously all the physics and timescales involved in a core flow history since its formation. The classical approach decomposes the global problem into well-defined restricted models addressing specific points. Then, the main obstacle to quantitative modelling and understanding stands in the extreme character of the involved physical dimensionless parameters, often inaccessible to both experiments and numerical simulations. Relevant studies rely on the general principle of dynamical similitude and scaling laws, sustained by asymptotic theory: rather than reproducing in a model the exact parameters of a planetary flow, the effort is focused on reaching the same dynamical regime. A systematic exploration of the parameter space then allows deriving generic scaling laws that are extrapolated towards planetary scales and challenged against available data. In this view, experimental models are extremely useful because they reach more demanding parameters (e.g. higher Reynolds number) than any simulation. Such experiments allow for the systematic exploration of the parameter space using very long data acquisition, suitable for statistical analysis. The drawbacks are of course the difficulty in data acquisition, as well as the limitations of accessible geometries and physics compared to simulations: e.g. how to make a radial gravity field in a spherical geometry in the laboratory?

In this review talk, I will present some recent works in experimental fluid dynamics relevant for core dynamics, focusing successively on:

- the fluid dynamics of core formation, including iron sedimentation and fragmentation and the related thermo-chemical equilibration during the latest stages of planet accretion;
- the fluid dynamics of core convection, including some non-classical aspects like the presence of a stratified layer or of a phase change;
- the fluid dynamics of core rotation, including the turbulence generated by tides, libration and precession.

My purpose will be to highlight the advantages and successes of the experimental approaches, but also the necessity of a collaborative multi-method approach that combines both experiments and numerics.

*Speaker

Quenching large-scale turbulent flows in planets with magnetic fields

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Abstract

Turbulence is ubiquitous in the fluid regions of planets and stars, where it is characterized by a vast range of spatiotemporal scales. A commonly observed process in rotating, hydrodynamic three-dimensional turbulence that leads to the formation of large-scale flows is the so-called inverse kinetic energy cascade. This process is thought to be responsible for the formation of large-scale vortices and zonal winds in the electrically insulating atmospheres of giant planets. However, the subsurface fluid regions of planets, and the entirety of most stars, are electrically conducting and capable of generating large-scale magnetic fields – it is unknown what role the inverse cascade plays in these systems. Here we show, utilizing a new asymptotic magnetohydrodynamic model, that sufficiently strong magnetic fields can saturate large-scale turbulent flows at a finite length-scale that is independent of the geometry. We derive a quantitative criteria to establish favourable conditions for the formation of domain-filling, large-scale vortices that extends previous, non-magnetic studies. The turbulence must overcome the ohmic dissipation introduced by the action of the magnetic fields on the fluid, as previously suggested. When our results are applied to the interiors of Jupiter and to the Earth's outer core, we conclude that commonly observed planetary magnetic field intensities, are likely enough to quench, and possibly prevent, the formation of large-scale flows.

*Speaker

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The Earth's inner core: a mineral physics perspective

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Abstract

Even since the work of Inge Lehmann and Francis Birch, we know that the Eath's inner core is a solid sphere made of an iron alloy. In the 1980's, it was discovered that it is also anisotropic: in average, seismic waves travel faster in the East-West than in the North-South direction, with an even more complex structure observed through repeated seismological studies. To this day, however, simple questions remain un-answered. What is the crystal structure of the inner core iron alloy? How old is the inner core? What is the dynamics of the inner core?

Mineral physicists attempt to investigate the physical properties of the Earth's inner core through high pressure / high temperature experiments, first-principles calculations, or the study of structural analogues. In this presentation, I will review recent studies on the structure, elasticity, and plasticity of the inner-core iron alloy. I will review our current understanding on the inner-core iron-alloy and how fine scale observations and modeling of seismic travel times could allow us to address issues regarding the age, dynamics, and structure of this remote region.

*Speaker

Jupiter's magnetic field morphology and implications for its dynamo

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Abstract

As of late 2017, Juno has collected magnetic field data from 8 perijove passes. With the near polar orbit around Jupiter, the roughly equal longitudinal spacing of the orbits and, most importantly, the close approach of Juno to Jupiter's dynamo (within about 20% of the planetary radius) these data provide an unprecedented view of an active dynamo. The initial results are unexpected. While these data might have been expected to reveal progressively smaller-scale structure in the field, instead what is seen is different.
First, at the top of the nominal dynamo region, we see large-scale field organization. Flux emerges from Jupiter's northern hemisphere in a relatively narrow band around 45 degrees N, and stretches across about 270 degrees of longitude. In contrast, in the southern hemisphere we see flux re-enter over a large diffuse region, in which the maximum radial flux is only a third of that seen in the northern hemisphere. Elsewhere (except near the equator), the radial field is much weaker, including at high northern latitudes.

Second, at the equator we see an extraordinarily intense and localized spot of negative flux, in which the radial flux is three times stronger than any other negatively signed flux. These inferences are robust, even at this early stage of analysis, though there may be unmodeled auroral field aligned currents, and other field sources presently under study.
Although the full 32 orbits planned for Juno will be necessary to reveal these features more fully, we will discuss the initial implications of these features for Jupiter's dynamo.

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Torsional deformation experiments at Mbar pressures using rotational diamond anvil cell

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Abstract

State-of-the-art static compression technology using diamond anvil cells enables the reproduction of high pressure conditions in a laboratory that are equal to or higher than those found in the deep Earth's interior. However, investigation of the dynamical (rheological) properties of the deep-Earth materials remains a technical challenge, especially under high pressures of the lower mantle and the core. Conventional diamond anvil cell experiments are limited mainly by the difficulty of achieving large strains under steady-state conditions, due to the coupling between deformation and pressure generation. We have developed large-strain, torsional deformation experimental system at Mbar pressures using rotational diamond anvil cell with nano-polycrystalline diamond anvils. Synchrotron X-ray laminography and diffraction measurements enable us to determine the strain and stress state within a sample *in-situ*. Preliminary experimental results on the rheological properties of the mantle materials at core-mantle boundary pressures will also be shown in this presentation.

*Speaker

Large-scale mantle structure: constraints from geodynamic models

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Abstract

The viscosity structure of Earth's mantle affects the thermal evolution of Earth, the ascent of mantle upwellings, sinking of subducted oceanic lithosphere, and the mixing of compositional heterogeneities in the mantle. We use a newly developed joint model of anisotropic Vs, Vp, density and transition zone topographies to generate a suite of solutions for the mantle viscosity structure directly from the seismologically constrained density structure. The density structure used to drive our forward models includes contributions from both thermal and compositional variations, including important contributions from compositionally dense material in the Large Low Velocity Provinces at the base of the mantle. These compositional variations have been neglected in the forward models used in most previous inversions and have the potential to significantly affect large-scale flow and thus the inferred viscosity structure. We use a Transdimensional, Hierarchical Bayesian inverse approach that allows us to consider the uncertainties in mantle tomography and forward modeling, and yields uncertainty estimates for the viscosity structure. Using new geodynamic models carried out with ASPECT, we will address the dynamical consequences of these viscosity structures and the conditions required to achieve Earth-like heat transport and large-scale mantle structure, including the change in radial correlation structure at depths near 1000 km.

*Speaker

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Probing the Earth's core dynamics through the assimilation of geomagnetic data into dynamo simulations

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Abstract

The geodynamo is a complex nonlinear system operating in the Earth's core, which can be solely observed through its magnetic field at and above the Earth's surface. Although direct data of the surface geomagnetic field are only available for the past four centuries, indirect observations from paleomagnetic records provide insights on the field over much longer time scales. These observations are often affected by errors induced either by experimental and dating uncertainties, or problems in separating the contributions of the different field sources. Estimating the deep core dynamics from such noisy surface data is a challenging dynamical inverse problem, which can be supported by prior information from dynamo simulations and tackled within a data assimilation framework. The Ensemble Kalman Filter (EnKF) provides an interesting approach to the data assimilation problem, given the high-dimensionality and nonlinear character of the geodynamo system. Within this approach, the error covariance necessary for the propagation of information from observable to hidden parts of the system is provided by an ensemble of dynamo models. In this talk, we will explore different aspects of geomagnetic data assimilation within an EnKF approach, beginning with synthetic experiments. We investigate, for instance, the convergence time of the assimilation given the direct and indirect observations, the impact on the dynamo simulation set up on the propagation of information from observations to the deep core, the resolution of the recovered flow structure and the predictability of the magnetic field forecasts. These analyses can provide important insights for the interpretation of the assimilation of geophysical data, such as geomagnetic field models based on modern or paleomagnetic observations. In particular, we focus on the possibility of retrieving information on the depth extent and longevity of the planetary scale gyre observed in core flow models, as well as predicting the long term evolution of the core's magnetic field, including specific features such as the South Atlantic Anomaly.

*Speaker

Geodynamo reversals and numerical simulations

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Abstract

More than 20 years ago, a stunning computer simulation of the geodynamo, including polarity reversals, has been published.
I will attempt to review the progresses made since then in terms of simulations, understanding of the mechanisms of the geodynamo and fit to observational constraints, with a focus on magnetic polarity reversals.
I wil also highlight open questions, and maybe a sneak peak on ongoing research.

*Speaker

Habitability from Tidally Induced Tectonics

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Abstract

The stability of Earth's climate on geological timescales is enabled by the carbon-silicate cycle that acts as a negative feedback mechanism stabilizing surface temperatures via the intake and outgas of atmospheric carbon. On Earth, this thermostat is enabled by plate tectonics that sequesters outgassed CO2 back into the mantle via weathering and subduction at convergent margins. Here we propose a separate tectonic mechanism – vertical recycling – that can serve as the vehicle for CO2 outgassing and sequestration over long timescales. The mechanism requires continuous tidal heating, which makes it particularly relevant to planets in the habitable zone of M stars. Dynamical models of this vertical recycling scenario and stability analysis show that temperate climates stable over Gy timescales are realized for a variety of initial conditions, even as the M star dims over time. The magnitude of equilibrium surface temperatures depends on the interplay of sea weathering and outgassing, which in turn depends on planetary carbon content, so that planets with lower carbon budgets are favoured for temperate conditions. Habitability of planets such as found in the Trappist-1 may be rooted in tidally-driven tectonics.

*Speaker

Anisotropy of the Earth's inner core from coda interferometry

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Abstract

Anisotropy of the Earth's inner core is a key to understand the evolution and dynamics of the core. Recently, using autocorrelations from earthquake's coda, we found an equatorial anisotropy of the inner-inner core (IIC), in apparent contrast to the polar anisotropy of the outer-inner core (OIC). To examine the validity of the extraction of core phases, we simulate coda interferometry using the one-dimensional synthetic coda of large earthquakes. Compared with the cross-correlations of real coda, the similarities among the simulated waveforms of the core phases (PKIKP, PKIIKP, PKPab, PKIKP2 and PKIIKP2) indicate that reverberations at first-order discontinuities constitute the major source for coda interferometry. Relative to synthesized Green's functions, the core phases derived from coda interferometry provide reliable phase information but varying amplitudes. To reduce possible contaminations from large Fresnel zone of the PKIKP2 and PKIIKP2 phases at low frequencies, we processed the coda (10,000_˜40,000 s after Mw> =7.0 earthquakes) from stations at low latitudes (within ±35°) during 1990 _˜ 2013. By imposing an automatic grouping strategy, the standard deviation normalization and a selection filter, we extracted 52 array-stacked high-quality empirical Green's functions (EGFs), an increase of over 60% from our previous study. The observed residuals are similar to the previous global dataset, including the fast axis and two low-velocity open rings, thus providing further support for the equatorial anisotropy model of the IIC. Speculations for the shift of the fast axis between the OIC and the IIC include: change of deformation regimes during the inner core history, change of geomagnetic field, and a proto-inner core.

*Speaker
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Crystal Structure and Equation of State of Fe-Si alloys under dynamic compression

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Abstract

The high-pressure behavior of Fe and Fe alloys is integral to our understanding of the formation and subsequent evolution of terrestrial cores. In this work, we employ ramped laser compression and in situ x-ray diffraction to measure the crystal structure and density of Fe-Si alloys at pressures and temperatures relevant not only to earth's core but also to larger super-earths. We will discuss the advances in experimental capabilities, outstanding challenges, and implications for inner core research.

*Speaker

Recent experimental developments for understanding the pressure-temperature-composition dependent anisotropic elastic properties of upper mantle minerals

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Abstract

Upper mantle is one of, if not the most anisotropic layer of the Earth's interior. It plays a key role in many surface or near-surface geological processes. The acoustically anisotropic nature of most mantle minerals is preferably believed to be the cause of the observed seismic anisotropy when flow-induced lattice preferred orientation (LPO) is present. Thus, investigations on the elastic anisotropy of mantle phases with the knowledge of LPO provide a unique insight into the chemistry and evolution of the Earth's interior. Recent technical developments, including CO2 laser-heating, application of new optical scattering geometry and use of focused ion beam in sample preparation, enables experimental studies of elastic anisotropy of various mantle minerals at high P-T condition. Based on these experimental data, the pressure, temperature and compositional effects on the elastic anisotropy of common upper mantle minerals are discussed. Examples include olivine, pyroxenes, amphiboles, and antigorite.

*Speaker