[S8-P01] Mantle convection with melting and freezing at either or both horizontal boundaries

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Abstract

Planetary mantles can be in contact with liquid oceans of similar composition, i.e. with phase change equilibrium at the boundary. This is the case of icy mantles in contact with an over- or under-lying ocean. This is also the case of silicate mantles that can be bounded above and/or below by magma oceans early in the planet's history. The possibility of phase change at a boundary of the mantle allows the matter to flow through. We have studied the Implications of the phase change boundary condition on mantle convection using linear stability analysis, a weakly non-linear approach and direct numerical simulations. The possibility of phase change at either or both boundaries decreases the critical Rayleigh number for the onset of convection and increases the associated wavelength. When phase change happens at both boundaries, a translation mode of convection is favoured. In a spherical shell, even with a phase change at only one boundary, a degree-1 mode of convection is favoured. The heat transfer efficiency also increases much more steeply with the Rayleigh number than the equivalent without phase change at the boundary.

*Speaker

[S8-P02] Global-scale water-carbon cycle in mantle dynamics and its implication to climate evolution

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Abstract

For revealing the long-term evolution of surface environmet in terrestrial planets (Earth, Mars, Venus and exosolar rocky planets), the global-scale carbon cycle across the deep interior plays a siginificant role in surface climate change, which has been pointed out from a coupled model of parameterized mantle convection and energy balance model for climate evolution (Tajika and Matsui, 1992; Franck et al., 2002). Recently, a climate regime diagram, as functions of degassing flux and distance between star and planet, has been proposed from a coupled model of evolution of deep planetary interior and climate by a series of investigations by Kadoya and Tajika (2015; 2016), which would be available for assessing habitable zone of exosolar planets. In spite of such a great progress on approaching the planetary system evolution, it is required to use a full dynamics model of mantle convection because it seems to be a bit difficult to express the various heterogeneous features that affect dynamics and heat transfer in the mantle dynamics. Here, for assesing how the deep planetary interior is senstive to the surface climate change and finding the habitable planet in various exosolar rocy planets, we develop a co-evolution model of deep planetary interior in full mantle dynamics model and climate evolution in zero-dimensional energy balance model. Using this type of modeling apporach, the surface climate would be somewhat sensitive to the reference value of carbon degassing flux associated with an amount of silicate weahering, which affects time-scale of snowball cycle on the surface. In the poster presentation, we'll discuss some sensitivities of climate evolution associated with evolution of deep planetary interior to distance from central star and surface plate motions.

*Speaker

[S8-P03] A dynamo model for small bodies considering different core crystallization regime

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Abstract

Core dynamics and associated dynamo action of small bodies such as Mercury, Mars, Moon and Ganymede are very unique compared with Earth-sized and even larger objects in various aspects. Most remarkable is the peculiar core crystallization regimes due to relatively low pressure and high sulfur concentration in the core. Inner core solidification at the ICB drives compositional convection, which dominantly powers the geodynamo, whereas iron solidification at the CMB known as iron snow, and a snow layer formation at a certain depth could drive dynamos of small bodies. It is suggested that these different types of buoyancy source could yield different types of convection and resultant dynamo. In this presentation, we report our numerical dynamo modeling results incorporating various types of driving mode of convection: iron snow and snow layer as well as ordinary iron solidification. In order to treat thermal and compositional buoyancy separately, we adopt double diffusive convection formulation instead of using the so-called codensity. Thermal-to-compositional diffusivity contrast is 10 as in our previous studies. Thermally or chemically stably stratified layer is imposed beneath the CMB. In case of iron snow, we find fingering-type convection within the thermally stably stratified layer, whereas an ordinary columnar-type convection occurs below the layer. Implications for small body dynamos are discussed in the presentation.

*Speaker

[S8-P04] Constraints on the lunar core composition and thermal state from geophysical data and thermodynamic properties of liquid iron-sulfur alloys.

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Abstract

A precise knowledge of thermodynamic properties of the lunar core is of prime importance for the ongoing efforts to reanalyze Apollo seismic data, for the interpretation of results from GRAIL and future projects to send seismometers to the lunar surface, and for understanding the thermal evolution of the Moon. Here we present a coherent thermodynamic model for liquid Fe-S alloys that is based on melting and recent thermoelastic data. From this model, densities and seismic velocites of liquid Fe-S alloys are calculated and liquidus temperatures are determined. We apply our model to infer the composition and present-day temperature of the lunar core from recent geodesy data by assuming a mantle density distribution deduced from lunar seismic data. Additionally we study the effects of our model on the thermal evolution of the core and evaluate the core's capacity to generate a magnetic field.

*Speaker

[S8-P05] Can precession in liquid-metal spherical cores drive planetary magnetic fields?

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Abstract

We perform numerical simulations of precession driven flows in spheres, trying to reduce the viscosity to reach regimes relevant for the liquid metal core of planets.
We test the capability of these flows to amplify and sustain a magnetic field. As more and more turbulence appears, we find that such dynamos are more and more difficult to find, while the magnetic field is produced at smaller and smaller scales.
We have not reached an asymptotic regime that could be safely extrapolated to planets, and so we cannot give a definitive conclusion. However, unless a radically different regime emerges at even lower viscosity, our findings suggest that planetary magnetic fields are unlikely to be driven by precession in spherical cores.
We also discuss how topography or deviation from sphericity may or may not change this picture.

*Speaker

[S8-P06] Inertial wave turbulence in planetary cores

Thomas Lereun[1], Benjamin Favier[1], Adrian Barker[2], and Michael Le Bars*[1]

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Abstract

Tides and libration are both capable of destabilizing the rotating flow in planetary cores via the so-called elliptical instability. The saturation of the elliptical instability has been shown to generate turbulence composed of nonlinearly interacting waves and strong columnar vortices with varying respective amplitudes, depending on the control parameters and geometry. Here, we present a suite of numerical simulations to investigate the saturation and the transition from geostrophic vortex-dominated to tridimensional wave-dominated regimes. This is achieved by simulating the growth and saturation of the elliptical instability in an idealized triply periodic domain, adding a frictional damping to the geostrophic component only, to mimic its interaction with boundaries. A wave-dominated regime that exhibits many signatures of inertial wave turbulence is characterized for the first time. This regime is expected in planetary interiors. The conclusions of our model are complemented by the first results from our libration experimental study, which indeed shows the possibility of this specific regime. Its consequences for the dynamics and dynamo of planetary cores are discussed. Ref.: Le Reun, T., Favier, B., Barker, A. J., & Le Bars, M. (2017). Inertial wave turbulence driven by elliptical instability. *Physical review letters*, *119*(3), 034502.

*Speaker

[S8-P07] The internal Cassini state of the Moon and its ancient dynamo

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Abstract

The librations and motions of the Moon have been extensively studied, especially in the decades following the Apollo missions where retroreflectors installed on the lunar surface allowed measurements with centimetre accuracy. The Moon's figure axis is tilted by 1.54 degrees with respect to the ecliptic, and the orbit normal is tilted by 5.145 degrees with respect to the ecliptic normal in the opposite direction. They both precess in a retrograde motion with a period of 18.6 years, keeping both axes nearly coplanar with the ecliptic normal thereby preserving a Cassini state. But despite the thorough research done on the Moon's rotational dynamics, because lunar laser ranging only measures the motions of the lunar surface little is known about its deep interior. We present a model which describes the internal rotational dynamics of a three layered moon subject to external torques and focus on the Cassini state. We show that because the frequency of the free inner core nutation (FICN) mode is within the resonance band of the 18.6 yr forcing period, the inner core tilt with respect to the mantle is likely large if there are no dissipation mechanism. The precise tilt angle depends sensitively on the frequency of the FICN which remains unknown. The inner core can be tilted further away than the mantle by up to 17 degrees, or in the reverse direction by up to 33 degrees. Our new model of the Cassini state allows us to calculate how the orientation of the mantle, inner core and spin axis of the fluid core may have changed as a function of the Earth-Moon distance. In particular, the misalignment between the mantle and the fluid outer core's rotational axes results in a differential velocity at the core mantle boundary (CMB), which has been suggested as a possible source of power for the ancient Lunar dynamo. A similar mechanism may have also occurred at the inner core boundary (ICB). We present calculations of how the magnetic Reynolds number associated with differential velocities at the CMB and ICB may have change with Earth-Moon distance for different Lunar interior models.

*Speaker

[S8-P08] The dynamo action of Jupiter's zonal wind system

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Abstract

The Juno mission is delivering spectacular data of Jupiter's magnetic field but it remains unclear from which depth the field originates. The new gravity data finally provide constraints on the depth of the zonal winds observed at cloud level. These winds could possibly contribute to the magnetic signal but their dynamo action remains little understood. In order to clarify these questions, we explore numerical dynamo simulations that yield Jupiter-like magnetic fields and concentrate on the Decaying Conductivity Region (DCR), the outer 10% of Jupiter's radius where the conductivity rapidly drops from the metallic value to much lower levels in the molecular hydrogen envelope. Our simulations show that the dynamo action is highly diffusive and therefore quasi stationary. The toroidal field clearly dominates while the locally induced current flows mainly in the latitudinal direction. The simple dynamics yields relations that provide high quality estimates for both the induced field and the electric currents. In a second step, we use these relations to estimate dynamo action in Jupiter's DCR. At about 0.965% of Jupiter's radius, the toroidal field reaches the level of the observed potential field. The locally induced poloidal field, however, is two orders of magnitude smaller. Radial field induction and Ohmic heating are particularly efficient near the strong surface field patch just south of the equator. The Juno spacecraft can potentially detect the related pattern that clearly reflect the zonal wind structure. A constraint based on the Ohmic heating suggest that the surface wind cannot reach deeper than 0.955% of Jupiter's radius.

*Speaker

[S8-P09] Turbulent dynamos in ellipsoids driven by mechanical forcing

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Abstract

Dynamo action in planetary cores has been extensively studied in the context of convectively driven flows. We show here that mechanical forcings, namely, tides, libration, and precession, are also able to sustain a magnetic field against ohmic diffusion. Previous attempts published in the literature focused on the laminar response or considered idealized spherical configurations. In contrast, we focus here on the developed turbulent regime and we self-consistently solve the magnetohydrodynamics equations in an ellipsoidal container subject to tides, libration, or precession. Systematic results for kinematic dynamos, and first successful results for full dynamos, are presented. Our work opens new avenues of research in dynamo theory where both convection and mechanical forcing can play a role, independently or simultaneously. Ref.: Reddy, K. S., Favier, B., & Le Bars, M. (2018). *Geophysical Research Letters*, *45*(4), 1741-1750.

*Speaker

[S8-P10] Magnetic Braking of Planetary Jet Flows

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Abstract

The azimuthally-directed zonal winds of the gas giants, Jupiter and Saturn, are amongst their most dominant surface features. Recent Juno gravity measurements have inferred that the zonal winds of Jupiter extend from the weather layer where they are observed down at least 3,000 km deep into the H-He molecular atmosphere[1]. Since these large-scale flow structures are characterized by low Rossby numbers (Ro $\approx$ 0.02), these zonal flows are likely at leading order in quasi-geostrophic balance. Thus, they extend into the molecular interior with little variation in flow velocity in the axial ˆz-direction and contain shears predominantly in the cylindrically radial ˆs-direction. In addition, Jupiters electrical conductivity increases smoothly as a function of spherical radius, r, as the molecular envelope transitions to a liquid metal[2]. As electrical conductivity increases, the strength of magnetic forces grows, which act as a resistive brake on the cylindrically-shearing azimuthal jet flows. The process of magnetic braking, thought to play a key role in the spherical truncation of the jets, will be quantified with this study. We have developed a pseudo-spectral code that solves the Cartesian Navier-Stokes equations in 2-D with buoyancy and a quasi-static magnetic field in the ˆy-direction. The numerical domain is periodic in the ˆx-direction, allowing ˆx-directed jet flows to develop. The obtained reduced model represents a slice of Jupiter's quasi-geostrophic interior in a plane perpendicular to the rotation axis, where the ˆx-directed jet flows that develop correspond to the azimuthal jets in a spherical shell geometry. To validate our numerical method, it is benchmarked against hydrodynamic and magnetohydrodynamic (MHD) linear theory, and against a fully nonlinear hydrodynamic case of shearing convection[3] . Then, we conduct direct numerical simulations (DNS) of shearing convection and vary the strength of the imposed magnetic field, whose intensity is controlled by the value of the Chandrasekhar number, Q, (estimated ratio of Lorentz and viscous forces) in order to investigate the effects of a magnetic field on the damping of the shear flow. In our first MHD case, carried out at Rayleigh number, Ra = 106 , Prandtl number, P r = 1 and Q = 103 , the ˆx-directed jet flows are strongly magnetically damped. The interaction parameter (the ratio of Lorentz to inertial forces), N = p Q2P r/Ra, is of order unity, suggesting that N may control the jet truncation. We are presently carrying out a broader survey of DNS cases over a range of Ra, P r, Q, and therefore N, to determine in detail under what conditions the quasi-static magnetic field damps the 2-D convective shear flows. Further in the future, electrical conductivity will be varied in the ˆy-direction to more accurately model magnetic braking processes occurring within Jupiter's deep interior.

*Speaker

[S8-P11] Anelastic torsional oscillations in Jupiter's metallic hydrogen region

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Abstract

Theory suggests torsional Alfven waves will be axisymmetric zonal flow fluctuations in the compressible, anelastic approximation; these waves have previously been examined for incompressible fluids in the context of the Earth's liquid iron core. Integrated theoretical models for the deep-seated Jovian dynamo, implementing radial changes of density and electrical conductivity from the molecular hydrogen envelope, have reproduced its strong, dipolar magnetic field. Adopting these models, we find anelastic torsional waves which travel in radius on timescales of several years or longer in the metallic region. They can propagate both inwards and outwards and be reflected at a magnetic tangent cylinder, enabling a standing 'oscillation'. This may distinguish the Jovian torsional waves from those in Earth's core, where observational evidence has suggested waves mainly travelling outwards. These waves can transport angular momentum to the overlying molecular region and possibly give rise to variations in the planet's length-of-day. Also, these internal perturbations can be revealed above the metallic region as changes in the zonal flow. Torsional waves in the interior could imprint themselves as flow variations at the surface.

*Speaker

[S8-P12] How deep is Jupiter's metallic hydrogen region region?

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Abstract

Recent observations from the Juno mission (Connerney 2018) have given much more accurate information about the Gauss coefficients of Jupiter's magnetic field than was previously available. The Lowes-Mauersberger spectrum of this new data can potentially be used to investigate where the top of the Jupiter's dynamo region lies. In the Earth, there is an abrupt change of electrical conductivity at the Core-Mantle boundary. If the transition between Jupiter's electrically conducting metallic hydrogen region and the insulating molecular hydrogen region region was sharp, it would be reasonable to assume that the magnetic spectrum was flat at the transition point, as this leads to a reasonably accurate estimate of the location of the Earth's Core-Mantle boundary. However, in Jupiter, unlike the Earth, the transition is not sharp. Models of the electrical conductivity of Jupiter have been developed by French et al. (2012) based on the ab initio density functional technique. These models show a gradual reduction of the conductivity as the metallic hydrogen transition region is approached from below, and a steeper fall off when the molecular hydrogen region is reached. We can compare the magnetic spectrum observed by Juno with the results of dynamo models using the French et al. conductivity model. This enables us to see how consistent the current electrical conductivity models are with the Juno data. We have also further explored the parameter space of our dynamo models, to see how sensitive the predicted magnetic spectrum is to variations in the dynamo parameters.

*Speaker

[S8-P13] Effects of neutral buoyancy outer boundary condition in models of deep convection in giant planets

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Abstract

Cloud motions have revealed strong east-west jet streams on Jupiter and Saturn. Two different paradigms have emerged for the origin of these jets. In the shallow dynamics paradigm zonal flow is driven largely by solar radiation and weather dynamics in the troposphere. In the deep convection paradigm forcing is thought to originate primarily via heat flow from the deep interior. Most previous anelastic models that focus on the development of deep zonal flows implement a constant entropy difference from the inner to outer boundary with no internal heat sources. For models with strong density gradients these constant entropy boundary conditions yield strong convective forcing at the outer boundary. However, observations indicate that giant planet tropospheres are stably stratified or perhaps near neutrally buoyant. Based on these observations we present here a deep convection parameter study with a zero entropy gradient (neutral stability) outer boundary condition and a uniform internal heat sink. We find that near convective onset, a neutrally buoyant shallow layer modifies the flow strongly, pushing active convection to occur near the bottom boundary. Furthermore, deeply seated jets develop efficiently, even with relatively weak forcing. Thus, for near critical and weak forcing the zero entropy gradient top boundary condition yields flows that resemble Boussinesq results, even for strong density gradients. For strongly convecting flows, the jet structure is more similar to cases with constant entropy difference. However, with strong convective mixing, the zero entropy gradient outer boundary condition results in relatively extensive regions of dynamical stability (reversed entropy gradient). Under these conditions, surface flows can develop with larger scale non-zonal features and vorticity structures that have planetary characteristics.

*Speaker
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[S8-P14] Rotating Convection in Anelastic Spherical Shell Models With a Stably Stratified Outer Layer

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Abstract

Observations from the current Juno space mission show that Jupiter's banded zonal flow has deep origins (Guillot et al., 2018). Galileo space mission measurements imply that Jupiter's troposphere is stably stratified (Magalhaes et al., 2002). This stable stratification can have a strong effect on the fluid dynamics of its atmosphere. Only recent studies have implemented the stably stratified fluid layer near the outer boundary to gain a further understanding of it. In our study, we use rotating anelastic convective spherical shell models and introduce this layer using the constant radial entropy gradient boundary conditions. To understand this layer's effects on the fluid dynamics of our models, we conduct a parameter study by varying the thermal forcing, density stratification, and stability near the outer layer. Based on our results, we were able to identify and classify five convective regimes, and determine some of the dependencies that the models exhibit when the stably stratified fluid layer is introduced.

*Speaker

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[S8-P15] Time-varying magnetic fields of Mercury

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Abstract

In this study we derive spherical harmonic models of Mercury's magnetic field from measurements of the MESSENGER mission. The derivation of such models suffers from a data distribution that is uneven in altitude and latitude, which leads to uncertainties in the model parameters. However, the presented time-averaged magnetic field model describes large scale external and internal magnetic fields and agree with previous descriptions of a strong axisymmetric internal field. The model also show a quadrupole-to-dipole ratio, that is very similar to the value reported by Thebault et al. (2018), though our modelling technique largely differs from their approach. The quadrupole-to-dipole ratio is found to be approximately 0.27 and may provide constraints for numerical dynamo simulations to obtain a Mercury-like core field.

To study the short-term variability of external and internal magnetic fields, residual data are derived by removing the steady field model from the measurements. These residual data are analysed by constructing spherical harmonic expansions of consecutive data subsets. Series of Gauss coefficients, which represent time-varying external and internal magnetic fields show periodic and highly correlated temporal variations that are caused by Mercury's orbital evolution around the sun. Further analyses of the time-varying magnetic field features suggest that a portion of the internal field variations could be related to induction processes in Mercury's mantle and/or iron core. Magnetic field generation in Mercury's exosphere may also contribute to the observed variation, but the density of electrically charged particles is rather low and the resulting magnetic signatures are expected to be weak and may not exceed a few nT.

We also investigate longer term variations of Mercury's magnetic field, i.e. its secular variation. For this purpose, we follow a different approach and derive a continuous field model, which is temporally parameterised by cubic B-splines. First results derived from MESSENGER data suggest that Mercury's internal magnetic field may show a feeble secular variation. The cause of the variation remains under investigation. If confirmed implications from these results for the dynamo process in Mercury's core will require further studies. The refined core field model also allows us to provide some prospect for the BepiColombo mission.

*Speaker

[S8-P16] Viscoelastic relaxation within the Moon and the phase lag of its Cassini state

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Abstract

In the year 1693, the Franco-Italian astronomer Giovanni Domenico Cassini published three empirical laws describing the orbital and rotational motions of the Moon. Cassini's Third Law describes the orientations of the Lunar Equatorial Plane and the Lunar Orbital Plane vis-'a-vis the Ecliptic. Specifically, it states that the lunar orbit normal and the lunar figure axis remain coplanar with the ecliptic normal. However, measurements from Lunar Laser Ranging (LLR) observations conducted in the decades following the Apollo missions unequivocally demonstrate the existence of a small 0.26 arc-second phase lag between the theoretical state (as described by Cassini) and the observed state of the Moon. This fact is suggestive of the existence of a dissipation mechanism within the Moon itself. Examples of previously proposed dissipation mechanisms include viscous dissipation in the Moon's fluid core and solid-body tides induced by the gravitational pull of the Earth and Sun. The objective of this study is to explain this phase lag in terms of a different dissipation mechanism, namely the viscoelastic relaxation which can occur in the solid regions of the Moon. This hypothesis is analyzed from the perspective of the angular momentum dynamics of the Moon and its constituent layers; a numerical model of the Moon is constructed, consisting of 5 homogeneous regions (a solid inner core, a fluid outer core, a low seismic velocity zone at the base of the mantle, a mantle and a crust). The model is constrained by the observed lunar mass, the moment of inertia of the solid Moon and other selenodetic and seismic observations. Viscoelastic deformations are incorporated into the angular momentum dynamics of the Moon. This is done by evaluating the elastic-gravitational equations and computing the appropriate deformation parameters (referred to as compliances). The goal is to recreate the observed phase lag solely from the effects of viscoelasticity in the appropriate lunar regions. Our approach enables us to determine the viscosity of the low seismic velocity zone, or that of the inner core, which is compatible with the observed phase lag.

*Speaker

[S8-P17] Investigating rheological models in the context of geophysical inversion for planetary structure

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Abstract

We investigate the use of different rheological models to describe the viscoelastic behavior in planetary mantles using geophysical observations. Rheology is strongly dependent on temperature and, as a consequence, imposes strong constraints on the interior structure of planets. In principle, shear modulus reduction and attenuation related to the viscoelastic relaxation occur as a result of dislocation creep and grain-boundary processes. Several rheological models have been proposed in the literature to describe these mechanisms. However, the choice of the most appropriate model to represent the dissipation in a planet's mantle remains an open issue. To examine this, we consider four different rheological models: extended Burgers, Andrade, Sundberg-Cooper, and a power-law approximation, and illustrate this for Mars. In order to construct geophysical models of Mars' crust and mantle, we compute elastic moduli and density by using self-consistent mineral phase equilibria calculations from which rock mineralogy and its elastic properties are predicted as a function of pressure, temperature, and bulk composition. These profiles are then combined with an Fe-S model applied to the core to build up the entire planetary model. Based on these interior structure and viscoelastic models, we can predict the corresponding geophysical response. Subsequently, we invert the available geophysical data for Mars (mean density, moment of inertia, tidal Love number, and global dissipation) for a set of model parameters representing the interior structure and viscoelastic behavior. For this, we employ a Bayesian approach to sample solutions to the inverse problem and determine the uncertainties. The results reveal that all of the aforementioned rheological models are capable of fitting the geophysical data. The resultant probability distributions for the major interior properties, such as core radius and composition, mantle thermal state, and crustal properties generally overlap for all investigated rheological models. The inversion results indicate that within the existing uncertainties and assumptions, the difference caused by the rheological models is less significant in determining interior structure. Models and data from other studies (e.g. seismology and geodynamics) can be combined with current study to improve the knowledge on the rheological models.

*Speaker

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[S8-P18] Dynamics of Enceladus' ocean projects the heterogeneous seafloor pattern to the base of the ice shell in polar regions

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Abstract

Several observations by the Cassini spacecraft at Enceladus pointed to the likelihood of ongoing hydrothermal reactions deep within the moon. The size of silicon-rich nano-particles in Saturn's environment suggests that hydrothermal products are quickly transported from the seafloor to the plume source. Numerical simulations of Enceladus' core by Choblet et al. (2017) show that, in the explored parameter range, tidal friction in the unconsolidated core results in narrow upwellings of hot water at the ocean seafloor that would promote hydrothermalism with a pattern that seems compatible with the observed surface properties of Enceladus. However, ocean dynamics could partly filter this strongly heterogeneous heat flux at the seafloor, mostly if rotational effects overcome thermal convection.

We present the results of 3D numerical simulations of the dynamics of Enceladus' ocean in which a laterally variable heat flow obtained from Choblet et al. (2017) is imposed at the bottom boundary. This pattern consists in the outward heat flow being concentrated in narrow " bands " located in the polar regions, with two bands joining both poles at the leading and trailing meridians. While the precise balance between the Coriolis and the buoyancy forces is not known, our first results demonstrate that although in some cases, the heat flux pattern at the seafloor can be significantly blurred at moderate latitudes bounded by the the tangent cylinder, it remains globally unaffected in polar regions where ocean plumes supply a significant amount of heat in regions coinciding with the lowest ice thickness. Scaling relationships also indicate that the transport time of organic products by ocean thermal vents would match the constraints derived from Cassini measurements (typically a few months).

*Speaker

[S8-P19] Formation of the lunar fossil bulges and its implication for the early Earth and Moon

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Abstract

First recognized by Laplace over two centuries ago, the Moon's present tidal-rotational bulges are significantly larger than hydrostatic predictions. They are likely relics of a former hydrostatic state when the Moon was closer to the Earth and had larger bulges, and they were established when stresses in a thickening lunar lithosphere could maintain the bulges against hydrostatic adjustment. We formulate the first dynamically self-consistent model of this process and show that bulge formation is controlled by the relative timing of lithosphere thickening and lunar orbit recession. Viable solutions indicate that lunar bulge formation was a geologically slow process lasting several hundred million years, that the process was complete about 4 Ga when the Moon-Earth distance was less than _˜32 Earth radii, and that the Earth in Hadean was significantly less dissipative to lunar tides than during the last 4 Gyr, possibly implying a frozen hydrosphere due to the fainter young Sun.

*Speaker

[S8-P20] Coupling between spin precession and polar motion of a synchronously rotating satellite

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Abstract

Existing angular momentum approaches for studying the polar motion, precession, and libration of synchronously rotating satellites, with or without an internal global fluid layer (e.g. a subsurface ocean), usually focus on one aspect of rotation and neglect coupling with the other rotation phenomena. We here develop, in an angular momentum approach, a consistent model that integrates all rotation variables and considers forcing both by the central planet and a potential atmosphere. The model variables chosen correspond most naturally with the free modes, although they differ from those of Earth rotation studies, and facilitate a comparison with existing decoupled rotation models that break the link between the rotation motions. The decoupled models perform well in reproducing the free modes, except for the Free Ocean Nutation in the decoupled polar motion model. We also demonstrate the high accuracy of the analytical forced solutions of decoupled models, which are easier to use to interpret observations from past and future space missions. We show that the effective decoupling between the polar motion and precession implies that the spin precession and its associated mean obliquity are mainly governed by the external gravitational torque by the parent planet, whereas the polar motion of the solid layers is mainly governed by the angular momentum exchanges between the atmosphere (e.g. for Titan) and the surface. To put into perspective the difference between rotation models for of a synchronously rotating icy moon with a thin ice shell and classical Earth rotation models, we also consider the case of the Moon, which has a thick outer layer above a liquid core. We also show that for non synchronous rotators, the Free Precession of the outer layer in space degenerates into the Tilt-Over mode.

*Speaker

[S8-P21] A time-averaged regional model of the Hermean magnetic field

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Abstract

This paper presents the first regional model of the magnetic field of Mercury developed with mathematical continuous functions. The model has a horizontal spatial resolution of about 830 km at the surface of the planet, and it is derived without any a priori information about the geometry of the internal and external fields or regularization. It relies on an extensive dataset of the MESSENGER's measurements selected over its entire orbital lifetime between 2011 and 2015. A first order separation between the internal and the external fields over the Northern hemisphere is achieved under the assumption that the magnetic field measurements are acquired in a source free region within the magnetospheric cavity. When downward continued to the core-mantle boundary, the model confirms some of the general structures observed in previous studies such as the dominance of zonal field, the location of the North magnetic pole, and the global absence of significant small scale structures. The transformation of the regional model into a global spherical harmonic one provides an estimate for the axial quadrupole to axial dipole ratio of about g20/g10=0.27. This is much lower than previous estimates of about 0.40. We note that it is possible to obtain a similar ratio provided that more weight is put on the location of the magnetic equator and less elsewhere.

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