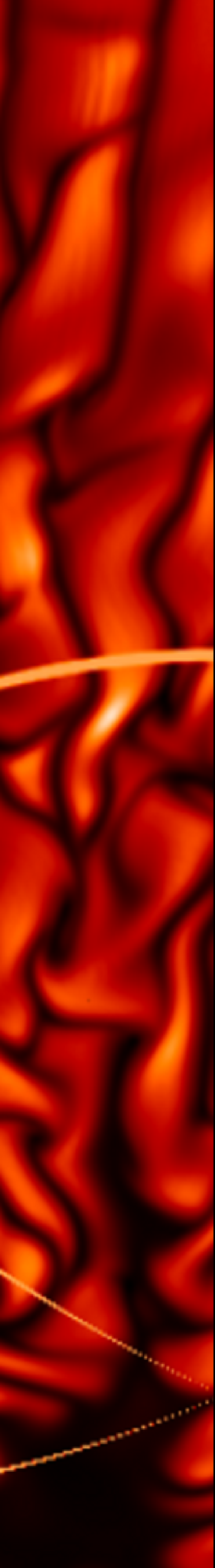

Stellar and Planetary Dynamos

Institut für Astrophysik
Universität Göttingen, Germany

26-29 May 2015

ABSTRACT BOOK

www.dynamos2015.de
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1 Abstracts: Talks

1.1 Session: Introduction to Dynamos

Tuesday, May 26, 9.10 am – 10.50 am, chair: Laurent Gizon

Stellar dynamos: differential rotation, cycle periods, and spots

Axel Brandenburg[1,2]

1: Nordic Institute for Theoretical Physics (Nordita)

2: Department of Astronomy, Stockholm University

There is widespread uncertainty about the nature of the global stellar dynamo: is it located essentially in the tachocline, or is the dynamo a distributed one, as recent global simulations suggest? A proper understanding of stellar activity requires a holistic approach in which the formation of active regions, spots, and the possibility of superflares are self-consistently included. In the tachocline scenario, the problem is avoided by postulating the existence of thin flux tubes that erupt to the surface and produce bipolar regions, but in the distributed dynamo scenario the large-scale field has a more diffuse nature and there are no extended flux ropes. Active regions would then need to be maintained by local processes.

In my talk, I will review both approaches, summarize the state of global dynamo simulations, and their coupling to the Sun's exterior through coronal mass ejections and the magnetized solar wind. Finally, I will review the current state of modeling magnetic flux concentrations as a phenomenon that is not deeply routed, as is commonly assumed. As common factors between stellar, planetary, and laboratory dynamos one can count the relative importance of kinetic and magnetic dissipation mechanisms for which I will present recent numerical results.

Mean fields versus local fields in convection dynamos

Andreas Tilgner[1]

1: University of Göttingen

Convection driven dynamos in plane layers provide examples of dynamos both with and without a mean field. Some care is necessary to distinguish the two cases because of statistical fluctuations in turbulent dynamos which always generate some mean field. The simple laminar, time independent and spatially periodic flows introduced byG.O. Roberts also contain examples of dynamos with and without mean fields.

The Babcock-Leighton solar dynamo

Manfred Schüssler[1], Robert Cameron[1]

1: Max Planck Institute for Solar System Research (MPS), Goettingen

Hale's polarity laws for sunspot groups, the helioseismic determination of differential rotation in the convection zone, and the success of surface flux transport models in reproducing the observed evolution of large-scale solar surface fields, together with a simple mathematical argument, yield compelling evidence that the large-scale solar dynamo operates according to the scenario originally envisaged by H.W. Babcock and R. Leighton in the 1960s. The polar fields represent THE poloidal field from which the toroidal flux emerging in sunspot groups is created by (mainly latitudinal) differential rotation. The polar fields themselves result from tilted sunspot groups while small-scale magnetic features do not provide a significant contribution.

The new concept of stellar spot-dynamo

Allan Sacha Brun[1]

1: Astrophysique Interactions Multi-échelles (AIM)

We present in this talk the new concept of stellar spot dynamo. Recent advances in 3-D numerical simulations have lead to dynamo solutions making more and more contact with real stars: these solutions possess cyclic bahavior, equatorward field propagation, organized large scale magnetic field. Yet stars possess spots and as of today no 3-D self-consistent dynamo simulations have yielded such magnetic features. We advocate that with the outcome of more powerful computers and better numerical treatment of the dissipation scales it is now possible to get dynamo solutions that generate self-consistently omega-loop like structure that can be seen as the progenitor of concentrated magnetic flux emergence, e.g starspot. We present such a solution and discuss it's difference with more classical global dynamo wave-like solutions.

1.2 Session: Stellar Dynamos (Theory) I

Tuesday, May 26, 11.20 am – 12.40 pm, chair: Laurent Gizon

Quiet Sun magnetism – What does it tell us about small-scale dynamos and their contribution to solar activity?

Matthias Rempel[1]

1: National Center for Atmospheric Research (NCAR), Boulder, USA

Small-scale magnetic field is ubiquitous in the solar photosphere and in its properties mostly independent from the solar cycle, i.e. the large-scale field component. While likely both, the large- and small-scale dynamos contribute to the observed magnetic field, recent research points toward a dominant contribution from a small-scale dynamo. I present a series of numerical simulations of small-scale dynamo action in the solar photosphere. It is found that an efficient small-scale dynamo operating just in the uppermost few Mm of the convection zone is not sufficient. The observationally inferred level of quiet Sun magnetic field implies small-scale dynamo action throughout the solar convection zone across all scales. Under these circumstances there is no clear separation between small- and large-scale dynamo action and vertical transport of mixed polarity magnetic field into the photosphere through convective upflows significantly influences the saturation field strength in the photosphere. In contrast to that, a net flux imbalance (i.e. magnetic flux from active regions) is found to have only a weak influence on the amount of mixed-polarity field in the photosphere. While the observed quiet Sun magnetic field is generally regarded as rather weak, models that are consistent with observations imply a convection zone that is magnetized close to equipartition. Consequently, already the small-scale field component alone, which is currently not sufficiently captured in most global dynamo models, has a significant influence on convective dynamics in the bulk of the convection zone.

Scaling laws in rotating convection

Laura Currie[1]

1: University of Exeter

Rotating convection occurs in many stellar and planetary interiors and is believed to play an important role in magnetic field generation through dynamo action. Despite large amounts of research, no comprehensive theory of rotating convection has been agreed on. Here we consider a simple Cartesian model of rotating convection and present physical arguments of a rotating mixing-length theory akin to those first proposed by Stevenson (1979) and more recently by Barker et al. (2014). The theory predicts properties of the bulk convection as a function of the imposed heat flux and rotation rate. We test the predictions with three-dimensional numerical simulations. We discuss modifications to the model to allow for more realistic effects, e.g., the role of density stratification, the interaction of the convection with a mean flow and the addition of a magnetic field.

Dynamo-action in massive stars: from the PMS to the TAMS

Alexander Kholtygin[1], Aleksei Medvedev[1], Swetlana Hubrig[2]

1: Saint Petersburg State University (SPbGU)

2: Leibniz-Institut für Astrophysik Potsdam (AIP)

The population synthesis code allowing to follow the evolution of the OBA magnetic stars from the pre-main sequence (PMS) stage to the end of the evolution of the star on the main sequence is developed. We study the changes of the stellar radii, masses, temperatures, effective magnetic fields and magnetic fluxes with age. We also developed a simple dynamo-action model at the PMS stage to reproduce the initial magnetic fields and fluxes distribution at the ZAMS. The distribution of the magnetic fields at the ZAMS appeared to be the log-normal. We suggest that with the increase of the age of the star its magnetic flux can dissipate. As a result of our simulations, the distribution of stellar magnetic fields from ZAMS to TAMS is obtained. The shape of this distribution is highly dependent on the rate of the magnetic field dissipation. It is shown that the model distribution of the magnetic filed of OBA stars is in agreement with that obtained from the analysis of the measured magnetic fields in these stars. The influence of the dynamo-action connected with the Yiron convection zone (FeCZ) at the formation of the stellar prominences is studied.

1.3 Session: Stellar Dynamos (Observations)

Tuesday, May 26, 2.00 pm – 3.20 pm, chair: Stefan Dreizler

Multi-wavelength picture of chromospheres and coronae on M dwarfs

Beate Stelzer[1]

1: INAF – Osservatorio Astronomico di Palermo

Studying the radiation emitted from the outer atmospheres of M stars is essential for understanding stellar dynamos that differ from the Sun, e.g. in the pre-main sequence stars where the stars rotate faster, in the fully convective regime where the solar-type dynamo mechanism is expected to break down, and in very cool stars where the matter motions may decouple from the magnetic field. Moreover, the high-energy emission related with stellar magnetic activity may be crucial for the evolution of planetary atmospheres and the evolution of life, in particular for planets around M stars which have their habitable zones at small separations. Yet, the strength of magnetic activity has not been calibrated across the whole electromagnetic spectrum and its dependence on stellar mass and age has remained widely elusive.

I present observations of magnetic activity on M dwarfs using a wide range of diagnostics of chromospheric and coronal emission in the X-ray, UV, optical and radio bands. The stellar samples cover a range of evolutionary phases from the pre-main sequence to the main-sequence. The aim of these studies is to establish connections between the emissions in different energy bands which probe different atmospheric layers and to determine how magnetic activity changes throughout the spectral sequence and throughout stellar evolution.

3D RMHD simulations of near-surface magnetoconvection in cool main-sequence stars

Benjamin Beeck[1]

1: Max Planck Institute for Solar System Research (MPS)

We have run three-dimensional radiative hydrodynamics (3D RMHD) simulations of the near-surface layers for a set of six cool main-sequence stars including the Sun. The average vertical magnetic field strength in the simulations ranges from 20G to the kG regime. The properties of small-scale magnetic flux concentrations as well as of starspots are investigated. We found, e.g., a lack of facular brightenings in M-star plage regions, significant differences in the limb darkening between the different stars, and a significant weakening of some spectral lines in bright magnetic flux concentrations in solar-like stars. The impact of the magnetic field on the local thermodynamical structure and the correlation between convective flows and magnetic field entail an impact on spectral lines (in addition to the Zeeman effect) which depends on the stellar parameters and on the local field strength. This impact is relevant for correctly interpreting spectroscopic and spectropolarimetric observations (e.g. ZDI inversions), which attempt to provide constraints for the underlying stellar dynamo.

Towards the understanding of the magnetic field properties in low-mass stars

Denis Shulyak[1]

1: University of Göttingen

Measuring surface magnetic field properties is a key to understand stellar dynamos and activity in low mass stars. However, cool temperatures, strong line blending, and often fast rotation strongly complicate analysis of stellar spectra. Here I will discuss recent results on the determination of the intensity and geometry of the magnetic fields in M-dwarfs and solar-type stars using IR observations obtained with CRIRES@VLT. The instrument provides unprecedented data of high resolution (R=100000) which is crucial for resolving individual magnetically broadened molecular and atomic lines.

1.4 Session: Stellar Dynamos (Theory) II

Tuesday, May 26, 3.50 pm – 5.10 pm, chair: Manfred Schüssler

Unified scaling relation for rising flux tubes in solar-like stars

Yori Fournier[1], Rainer Arlt[1]

1: Leibniz Institute for Astrophysics (AIP)

In the frame of a Babcock-Leighton dynamo, the missing link is how magnetic flux is transported from the bottom to the top of the solar convection zone. One possible way is by means of coherent magnetic flux tubes. Even though magnetic flux tubes have been studied extensively for a few decades, their dynamics is still not fully understood, particularly in 3D. Here we would like to present a scaling relation for the transport time scale of magnetic flux in the convection zone of solar-like stars. We find it to be a robust result which could help constrain the B-L dynamo.

Possible Near-Surface Shear Layers on Low-Mass Stars

Maria Weber[1], Matthew Browning[1], Kyle Augustson[2]

1: University of Exeter

2: National Center for Atmospheric Research (NCAR), Boulder, USA

Helioseismology has revealed that the solar differential rotation profile exhibits an outward decrease in angular velocity of 4% from 0.95R to R at low latitudes. This near-surface shear layer (NSSL) is thought to play a significant role in defining the nature of large-scale convective patterns and the observed magnetism of the Sun. We explore the existence of NSSLs in low-mass (0.05 to 1.2 solar mass) stars by first analytically identifying the possible thickness and shear of such layers as a function of rotation rate and mass. We also perform simulations to assess the nature of the differential rotation profile across the outer 10% in radius of a solar-like star utilizing the new Compressible Spherical Segment (CSS) code, capable of capturing 3D compressible MHD convection within a rotating spherical shell segment. These simulations tend to preserve constant angular momentum across the domain. However, this scenario does not adequately describe the solar NSSL. In addition to angular momentum transport, meridional forces may play an essential role in determining the shear across the NSSL. By informing future CSS simulations with downflow plume networks from above and large-scale convection from below, a more realistic model of NSSLs may be obtained.

Observational constraints on the solar dynamo

Robert Cameron[1]

1: Max Planck Institute for Solar System Research (MPS)

We will discuss what we have recently learned from observations about the solar dynamo.

A reassessment of the depth of the solar Maunder minimum

Rainer Arlt[1], Ilya Usoskin[2], Jose Vaquero[3]

1: Leibniz Institute for Astrophysics Potsdam

2: University of Oulu

3: Universidad de Extremadura - Uex (SPAIN)

Grand minima pose a challenge to dynamo solutions and provide additional constraints besides solar and stellar cycles. The solar Maunder minimum (from 1645 to 1715 approximately) is the only directly observed grand minimum on the Sun. Recently, the very low activity level during that period was questioned. While the current data set for that time (group sunspot number by Hoyt & Schatten 1998) underestimates the activity slightly, we demonstrate by means of original observational notes, that the sunspot number was indeed very low during the Maunder minimum and that a period like that has never been observed since then. The findings are backed up by records of aurorae and cosmogenic isotopes.

1.5 Session: Planetary Dynamos I

Wednesday, May 27, 9.00 am – 10.40 am, chair: Ulrich Christensen

Low viscosity and no viscosity fluid dynamics of Earth's core

Andy Jackson[1], Andrey Sheyko[1], Kuan Li[1], Phil Livermore [2]

1: ETH Zürich 2: University of Leeds

Planetary dynamos operate in a regime where the effect of viscosity are negligible. We report on two approaches to the problem of numerically simulating this regime appropriately. In the first method, we drop the value of the Ekman number, measuring the effect of viscous forces compared to Coriolis forces, to the smallest value possible given current computer resources. This also enables us to reduce the value of the magnetic Prandtl number significantly below unity, leading to scale separation between velocity and magnetic fields. We report on dynamo solutions in this regime as a function of different strengths of thermal driving, measured by the Rayleigh number. In the second approach we embrace the ideas propounded by J.B. Taylor in 1963, namely to consider the inertialess inviscid limit in which there is an exact balance between Coriolis, pressure, Lorentz and buoyancy forces. This limit, termed magnetostrophy, can be considered as a good approximation to the physics of the Earth's core. We report on a methodology that is able to handle the technicalities that arise under this particular approximation.

Flow Instabilities in Spherical Couette System

Ankit Barik[1], Johannes Wicht [1]

1: Max Planck Institute for Solar System Research (MPS)

We consider different regimes of the spherical couette system - no or low, intermediate and fast outer boundary rotation. For each, we consider both types of inner sphere rotation - prograde ($\Delta\Omega > 0$) and retrograde ($\Delta\Omega < 0$). For slow Ω outer, both show the advent of an equatorial jet instability. The width of the jet scales the same as the boundary layer thickness ($Re^{-0.5}$). The torque scaling is compared with experimental scaling obtained from the 3 metre experiment at Maryland. Upon increasing the outer boundary rotation rate, we see fundamentally different instabilities depending on the direction of inner sphere rotation (Stewartson layers, helical instabilities, inertial modes). To further get closer to the experiment, we now apply an axial magnetic field and find that as the magnetic field gets stronger, the velocity fields of the inertial modes lose their original symmetry. The critical $\Delta\Omega$ needed for onset of first non-axisymettric instability and the critical wavenumber at onset scale as a power law for both prograde and retrograde rotation.

Dynamo bifurcation and saturation mechanisms in rotating spherical shell

Ludovic Petitdemange[1]

1: École Normale Supérieure (ENS)

We investigate the nature of the dynamo bifurcation in a configuration applicable to the Earth's liquid outer core and other planetary interiors, i.e. in a rotating spherical shell with thermally driven motions of a Boussinesq fluid. We discuss the nature of the bifurcation and the different dynamo branches. We highlight the existence of a subcritical strong-field branch which is relevant for planetary dynamos because the Lorentz force is mainly balanced by the Coriolis force (Magnetostrophic regime). We have performed a systematic study of this new strong-field branch. We show that the dynamo bifurcation and the saturation mechanism for the classical dynamo branch (weak-field branch) depend on the control parameters numerically accessible (which unfortunately remains remote from geophysical application), and we show that viscosity and inertia always play an important role in simulations.

Dipolar dynamos in stratified systems

Raphaël Raynaud[1,2], Ludovic Petitdemange [1,2], Emmanuel Dormy [1,3]

1: Laboratoire de Radio Astronomie de l'ENS (LRA)

2: Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique (LERMA)

3: Institut de Physique du Globe de Paris (IPGP)

Observations of low-mass stars reveal a variety of magnetic topologies ranging from large-scale, axial dipoles to more complex magnetic fields. Spherical simulations of convective dynamos reproduce a similar diversity, either with Boussinesq or anelastic models taking into account the variation of the density with depth throughout the convection zone. A conclusion from anelastic studies is that dipolar solutions are difficult to obtain as soon as substantial stratifications are considered. We rely on a systematic parameter study to investigate in more detail the impact of the density stratification both on the dynamo onset and the dipole collapse. Our study indicates that the loss of the dipolar branch does not ensue from a modification of the dynamo mechanisms related to the background stratification, but could instead result from a bias as our observations naturally favour a certain domain in the parameter space characterized by moderate values of the Ekman number, owing to current computational limitations. We also show that the critical magnetic Reynolds number of the dipolar branch is scarcely modified, which provides an important insight into the global understanding of the impact of the density stratification on the stability domain of the dipolar dynamo branch.

1.6 Session: Laboratory Dynamos

Wednesday, May 27, 11.10 am – 12.30 pm, chair: Manfred Schüssler

Studying dynamo mechanisms using liquid metals and unmagnetized plasmas

Mark Nornberg [1]

1: University of Wisconsin-Madison

Stellar and planetary magnetic fields arise from various fluid processes including rotation, shear, convection, and buoyancy to produce flows which provide amplification of magnetic flux and a feedback mechanism to sustain growth of the magnetic energy. Experimental dynamos using liquid sodium have demonstrated the impact of turbulent fluctuations on the transport of magnetic flux through an effective enhancement to the rate of resistive diffusion. Direct measurements of the vector turbulent emf in an impeller-driven flow in the Madison Sodium Dynamo Experiment with both shear and isotropic turbulence show that the emf is anti-parallel to the mean current and scales with the velocity fluctuations and correlation lengths as does the turbulent resistivity derived from quasi-linear theory. This enhanced dissipation, while being detrimental to the slow dynamo at threshold conditions, is a critical element of fast dynamos which rely on turbulence to relax magnetic stress. In rapidly rotating flows, however, the presence of strong shear can suppress these turbulent fluctuations and completely eliminate any enhanced dissipation effects as observed in the New Mexico Tech Taylor-Couette Experiment. Unmagnetized plasmas, unlike liquid metals which have a fixed viscosity and resistivity, provide a means to control the relative viscous and resistive dissipation rates through density and temperature. The Madison Plasma Dynamo Experiment uses a novel multi-cusp confinement strategy to create rapidly rotating, hot, dense plasmas where the ions are unmagnetized to facilitate creating dynamos at high magnetic Reynolds number in either viscous or turbulent flows.

The time irreversibility of turbulence

Eberhard Bodenschatz[1]

1: Max-Planck-Institut für Dynamik und Selbstorganisation (MPIDS)

Triadic resonances in numerical simulations of a precessing cylinder

Andre Giesecke[1]

1: Helmholtz-Zentrum Dresden Rossendorf (HZDR)

In the framework of the project DRESDYN (DREsden Sodium facility for DYNamo and thermohydraulic studies) a next generation dynamo experiment is under construction at the Helmholtz-Zentrum Dresden-Rossendorf. In this experiment a fluid flow of liquid sodium in a cylindrical container, solely driven by precession, is considered as a possible source for magnetic field generation.

Precession has long been discussed as a complementary energy source for driving the geodynamo, and dynamo action generated by precession driven flows has been found in various numerical simulations in a sphere, ellipsoid, cube and cylinder. In the current study we perform hydrodynamic simulations of the three-dimensional non-linear Navier-Stokes equation in cylindrical geometry including weakly precessional forcing. The main focus is put on the development of the non-axisymmetric time-dependent instabilities that could be responsible for dynamo action like triadic resonances.

Our simulations reveal clear triads at aspect ratios and frequencies close to predictions from the linear inviscid theory with an amplitude below the forced m=1 mode so that most of the flow energy remains in the fundamental forced mode. Next step will be kinematic simulations in order to test the ability of the triades to provide for dynamo action.

1.7 Session: Stellar Dynamos (Observations) II

Thursday, May 28, 9.00 am – 10.40 am, chair: Sandra Jeffers

Stellar rotation, activity and dynamos form CoRoT and Kepler

Rafael Garcia[1]

1: Laboratoire AIM, CEA / DSM – CNRS - Univ. Paris Diderot – IRFU / SAp, Centre de Saclay

Continuous high-precision photometry represents a unique way to study stellar dynamics at different time scales. Their detailed study allows us to characterize surface rotation, convection, and photospheric magnetism which are the main ingredients of stellar dynamos. In the case of Kepler, observations are as long as 4 years allowing us to study stellar magnetic activity (and cycles) for rapidly rotating stars, for which we could expect short magnetic cycles of a few years and therefore accessible to our current length of observations. With the advent of asteroseismology, a new window on the internal properties of stars is opened, in particular, to the size of the convection zones, which is one of the key parameter to understand stellar magnetism and dynamos. Moreover, in some stars we are also able to infer the internal rotation. In this talk I review the present status of the analysis of the photospheric activity measured on CoRoT and Kepler solar-like stars, separating them into three categories: young and hot (F) solar-like stars, main-sequence (G) stars, and subgiants. I will end by reporting some interesting results obtained from seismic analysis that can also be used as a complement to understand the magnetism of stars and their dynamos.

Solar turbulent convection at supergranulation scale

Jan Langfellner[1], Laurent Gizon[1,2], Aaron Birch[2]

1: Georg-August-Universität Göttingen, Institut für Astrophysik (IAG)

2: Max-Planck-Institut für Sonnensystemforschung (MPS)

Stellar dynamos are maintained by fluid motions at various spatial scales, including turbulent convection. Thus it is important to understand the collective properties of convection cells such as supergranules. We present observational results on the dynamics of the average supergranule in the Sun based on data from the HMI instrument on the SDO spacecraft. We find that the average supergranule tends to rotate clockwise in the northern hemisphere and counter-clockwise in the southern hemisphere, consistent with the action of the Coriolis force. Surrounding horizontal inflows rotate in the opposite direction. The vertical vorticity in the inflows is stronger and more localized than in the outflows. Further, the magnetic field in the inflows (network field) at the equator is not distributed isotropically around the average supergranule, but is stronger in the west. This is presumably connected to the observation that the supergranulation pattern rotates faster around the Sun than magnetic features. Such an anisotropy is also found in measurements of the downflow velocity (stronger downflows west of the average supergranule), supporting the idea of an intimate relationship between the magnetic field and the fluid motions on supergranulation scale.

Recent Results From Global Mode Helioseismology

Jesper Schou[1], Tim Larson[2]

1: Max Planck Institute for Solar System Research (MPS)

2: Stanford University

One of the ways to probe important aspects of the solar dynamo is to use global mode helioseismology. To that end we have recently completed a reanalysis of the 15 years MDI data with substantially reduced systematic errors and have just analyzed 5 years of HMI data. Here we will show some of the results obtained from this analysis and describe our progres on extending the analysis back in time using data from Mt. Wilson Solar Observatory.

Asteroseismic inversions for rotation of Sun-like stars: sensitivity to uncertainties

Hannah Schunker[1], Warrick Ball[2], Jesper Schou[1]

1: Max Planck Institute for Solar System Research (MPS)

2: Georg-August-Universität Göttingen, Institut für Astrophysik (IAG)

There are two sources of observational uncertainty in linear asteroseismic inversions for the interior rotation: constraining the stellar models and measuring the rotational splittings. The sensitivity of the inversion results to these combined uncertainties has not been evaluated. We quantify the effect of observational spectroscopic and asteroseismic uncertainties on linear inversions for internal radial rotation of the Sun-like star HD 52265, and early giant star KIC 7341231 using stellar models and synthetic rotation profiles to generate rotation sensitivity kernels and synthetic mode splittings.
We found that inversions for the solar-like radial rotation of HD 52265 are dominated by the uncertainties in the observed rotational splittings. When the rotation rate near the interior is increased to six times that of the surface rotation rate this is no longer the case. However, for KIC 7341231, the sensitivity of the inversions to an improper stellar model are comparable with the sensitivity to the rotational splitting uncertainties.

1.8 Session: Star-Planet Interaction

Thursday, May 28, 11.10 am – 12.30 pm, chair: Ansgar Reiners

Stars and exoplanets: interaction, rotation, activity

Katja Poppenhaeger[1]

1: Harvard-Smithsonian Center for Astrophysics (CfA)

The architecture of extrasolar planetary systems often differs strongly from our own solar system. Many exoplanets orbit their host stars at close distances, with semi-major axes of only a few stellar radii; this can influence the evolution of the planetary atmospheres as well as the evolution of the host stars themselves. While cool stars usually spin down with age and become inactive, an input of angular momentum through tidal interaction, as seen for example in close binaries, can preserve high activity levels over time. This may also be the case for cool stars hosting massive, close-in planets. A variety of magnetic interaction scenarios has also been explored in models. However, selection effects from planet detection methods may skew the activity levels seen in samples of exoplanet host stars, so caution is warranted. Recent observational advances have made it possible to study these effects in an unambiguous manner, with intriguing results on the evolution of host star activity and mass loss of exoplanetary atmospheres. I will conclude with an outlook of how our emerging insights into stellar ages, magnetic activity, and exoplanet atmospheres will lead to a comprehensive understanding of exoplanet systems.

Interaction between exoplanets and stellar winds

Aline Vidotto[1]

1: Université de Genève

The interplanetary space is permeated by stellar winds, whose properties are crucial to constrain their interactions with exoplanets and also essential for the study of space weather events on exoplanets. Although the great majority of exoplanets discovered so far are orbiting cool, low-mass stars with properties (mass, radius and effective temperatures) similar to solar, the dramatic differences in stellar magnetic activity, added to the close orbits of the vast majority of detected exoplanets, can make the interplanetary medium of exoplanetary systems remarkably distinct from the one present in the Solar System. In this talk, I will present the progress being made in data-driven modelling of stellar winds, showing that the interaction of the stellar winds with exoplanets can lead to several observable signatures, some of which that are absent in our own Solar System.

A search for H_3^+ emission from hot Jupiter atmospheres

Feo Lenz[1]

1: Georg-August-Universität Göttingen, Institut für Astrophysik (IAG)

Hot Jupiter atmospheres are expected to cool their thermospheres by the emission of H_3^+ in NIR wavelengths, similar to the well-known emission on Jupiter. The close distance of these planets to its host star results in highly increased stellar irradiation of the planets atmosphere. This is expected to lead to much higher H_3^+ emission rates than known from Jupiter. Theoretical simulations predict intensities of H_3^+ emission that scatter by several orders of magnitude between different models, but so far, no emission signatures were detected in the few observations carried out. We present our search for H_3^+ emission from extrasolar giant planet atmospheres using CRIRES at the VLT and discuss the possibilities with current and future ground based instrumentation to push the sensitivity down to the limit of theoretical predictions.

1.9 Session: Planetary Dynamos II

Thursday, May 28, 2.00pm – 3.20 pm, chair: Benjamin Beeck

Waves in the Earth's Core

Chris Jones[1]

1: University of Leeds

At present, the only part of the Earth's magnetic field that is well known is that outside the liquid metal core where it is generated. The detection of waves in the core could potentially tell us much more about the magnetic field in the Earth's deep interior. There is good evidence that axisymmetric torsional Alfven waves have been detected both in the geomagnetic secular variation and in the length of day signal. This tells us about the component of the magnetic field pointing radially outwards from the rotation axis. Torsional oscillations have been found in dynamo and magnetoconvection simulations, and this has enabled us to identify the excitation mechanism generating these waves, at least in the models. The waves originate primarily from the tangent cylinder, the cylinder coaxial with the rotation axis that encloses the solid inner core.

Nonaxisymmetric waves are likely to exist in the core also, but they have not yet been unambiguously identified, as it is hard to distinguish between wave propagation and advection of magnetic features due to mean flows generated by convection. However, these nonaxisymmetric waves are also seen in simulations, and these can be used to suggest which parts of the secular variation are likely dominated by wave propagation rather than advection. Waves can also potentially shed light on the question of whether some parts of the core are stably stratified, as has been suggested.

A parameter study of Jupiter-like dynamo models

Lúcia Duarte[1]

1: College of Engineering , Mathematics and Physical Sciences, University of Exeter (CEMPS)

The upcoming space missions to Jupiter will provide new information about the outer flow dynamics and magnetic field of the planet. In the last few years, the interest in more accurate numerical models of the planet significantly increased and models remarkably close to the observations have been developed which incorporate interior radial profiles obtained from ab initio equations. The solutions of these dynamical numerical models already show several surface features that closely reproduce the observational data available now. Future observational data will provide better constraints for numerical models, thus allowing comparisons at a much higher degree. In the mean time, the next step in the numerics is to develop parameter studies, which will provide us a broader range of models incorporating Jupiter's interior profiles. Simplifications are necessary when it comes to numerical modelling and so we present here an extensive parametric study of numerical models which assume a realistic equation of state, along side previously published dynamical models which assume a simplified polytropic reference state for comparison. We perform a parameter study varying the Ekman number and the Prandtl numbers at different supercriticallies. Furthermore, for a more detailed analysis we focus on different heating mechanisms for the Jupiter-like interior models.

Explaining Jupiter's internal dynamics

Thomas Gastine[1], Johannes Wicht[1], Lúcia Duarte[1,2], Moritz Heimpel[3]

1: Max Planck Institute for Solar System Research (MPS)

2: University of Exeter

3: University of Alberta

Data from various spacecrafts revealed that Jupiter's large scale interior magnetic field is very Earth-like. This is surprising since numerical simulations have demonstrated that, for example, the radial dependence of density, electrical conductivity and other transport properties, which is only mild in the iron cores of terrestrial planets but very drastic in gas planets, can significantly affect the interior dynamics. Jupiter's dynamo action is thought to take place in the deeper envelope where hydrogen, the main constituent of Jupiter's atmosphere, assumes metallic properties. The potential interaction between the observed zonal jets and the deeper dynamo region is an unresolved problem with important consequences for the magnetic field generation. Here we present a numerical simulation that is based on recent interior models and covers 99% of the planetary radius (below the 1 bar level). Simulated dynamo action primarily occurs in the deep high electrical conductivity region, while zonal flows are dynamically constrained to a strong equatorial jet in the outer envelope of low conductivity. For the first time, our model reproduces the structure and strength of the observed global magnetic field and predicts that secondary dynamo action associated to the equatorial jet produces banded magnetic features observable by the Juno mission.

1.10 Session: Planetary Dynamos III

Thursday, May 28, 3.50 pm – 5.10 pm, chair: Jörn Warnecke

Observational constraints on Planetary dynamos

Richard Holme[1]

1:Department of Earth Ocean and Ecological Sciences, University of Liverpool

Models of planetary magnetic fields constrained by observations present many features that can be considered against theoretical models, many of which receive little attention. Whether these featuers all involve turbulence is unclear; however, many involve magnetic structure which is at least below the level of observation, and an increasing number involve flow instability, another feature of the SPP. In this presentation I consider a number of observations, some new, some rather old, from different planets, that require a better theoretical framework. These include:

1) Instability in a stably stratified layer at the top of the core.
2) The spectrum of the geomagnetic secular variation.
3) The structure of the magnetic field and secular variation of Jupiter.
4) The lack of symmetry of the magnetic fields of Uranus and Neptune.

Long-term dipole field variations in geodynamo simulations: a statistical approach

Domenico Meduri[1], Johannes Wicht[1]

1: Max Planck Institute for Solar System Research (MPS)

The geomagnetic field varies over a broad range of time scales ranging from one year to tens of millions of years. The most dramatic changes in the dipole field occur on millennial time scales and are associated with reversals and excursions. However, due to the quality of paleomagnetic data available, the long-term field behavior still remains poorly constrained. Self-consistent numerical simulations of the geodynamo permit to investigate the field variability on millennial and longer time scales in much greater detail. Here we study the dipole moment variations in several extremely long numerical dynamo simulations to explore the statistical properties of reversals and excursions. Simulated reversals are characterized by a transition from a high to a low axial dipole moment state. We propose a Gaussian model that consistently describes these states and we compare the time scales of dipole decay and growth. Using a Bayesian approach, we show that a Poisson process best describes the occurrence of reversals. Excursions characterized by relatively large dipole intensity drops are statistically identical to reversals and likely have the same internal origin. The simulations suggest that both events are simply triggered by particularly strong axial dipole fluctuations while other field components remain largely unaffected.

A dynamic inner core boundary condition for terrestrial dynamo simulations

Johannes Wicht[1], Ajay Manglik[2]

1: Max Planck Institute for Solar System Research (MPS)

2: CSIR-National Geophysical Research Institute

Latent heat and light elements released from a growing solid inner core play an important role for driving the geodynamo. Classical dynamo simulations often combine compositional and thermal driving into one variable called codensity. Either a constant codensity or a constant codensity flux is then assumed as a lower boundary condition. However, the local inner core growth should depend on the local cooling rate and thus on the local convection. Heat and compositional flux from the inner boundary therefore couple to the outer core dynamics and vary in space and time. This coupling can be expressed via a dynamic lower boundary condition that parameterizes the inner core growth and depends on a new dimensionless number that we call dynamic dissipations number D. Numerical simulation at different dynamics dissipation, Ekman and Rayleigh numbers showed that the solutions are similar to classical approaches assuming a fixed codensity flux for $D<1$. However, recent estimates of inner core properties suggest a value around $D=2$ where the dynamics deviates significantly from classical approaches. The new condition tends to promote a rather homogeneous inner core growth and can also influence the reversal behavior.

Vortices and Zonal Flow in a Model of Jupiter With Shallow Stable Stratification and Deep Convection

Moritz Heimpel[1]

1: University of Alberta

Global magnetic fields of planets and stars are sustained by a dynamo process, which is driven by deep convection of electrically conducting fluid in cooling bodies. In the dynamo regions of Jupiter and Saturn high electrical conductivity limits, via magnetic braking, the zonal flow velocity. However, deep convection that extends outward into the semiconducting molecular envelope can drive fast, East-West zonal flows. While planetary jets and vortices have been studied for over 350 years, their origin and dynamics are still vigorously debated. Previous dynamical models of giant planet atmospheres have been of two classes. Shallow flow models produce jets and vortices from 2D turbulence in a very thin spherical layer, but require special conditions to reproduce observed equatorial superrotation. In contrast, deep convection models generically reproduce equatorial superrotation, but lack coherent vortices, which do not survive the formation of jets. We attempt to unify these two approaches using a 3D spherical shell compressible fluid numerical model, driven by convection at depth, but grading to a stably stratified shallow layer. We find that jets originate and are sustained in the convective interior, which spawns convective plumes that travel upward and generate coherent vortices confined to the shallow layer.

1.11 Session: Stellar Dynamos (Observations) III

Friday, May 29, 9.00 am – 10.40 am, chair: Ansgar Reiners

Stellar magnetism: Learning loops between the Sun, distant stars and planets

Svetlana Berdyugina[1]

1: Kiepenheuer-Institut für Sonnenphysik

Understanding stellar magnetism is now a joint effort of the solar, stellar and planetary communities, and this workshop is a realization of it. Each of the communities have their own goals, assumptions and methods. Each produce an immense amount of results. In this talk I will attempt to assess the current results, assumptions and strategies while trying to identify learning loops to be yet explored.

Observing magnetic cycles on Solar-type stars

Sandra Jeffers[1]

1: Georg-August-Universität Göttingen, Institut für Astrophysik (IAG)

The BCool project is an international collaboration studying the magnetic activity of low-mass stars from pre-main sequence through to evolved objects and using spectropolarimetric observations to directly characterise the large-scale magnetic fields of cool stars using Zeeman Doppler imaging. From our long-term monitoring of the large-scale magnetic field over nearly 10 years, we are starting to see cyclic behaviour in several targets. In this presentation I will show our results and highlight a few cases we find surprising cyclic behaviour compared to the Sun.

Modelling stellar brightness variations

Alexander Shapiro[1], Sami Solanki[1,2], Natalie Krivova[1]

1: Max Planck Institute for Solar System Research

2: School of Space Research, Kyung Hee University

We develop a model that attributes the variability of the stellar brightness to the imbalance between the contributions from dark starspots and bright faculae. Our approach is based on the assumption that the photometric variability of Sun-like stars has the same basic causes as the Sun's so that we can describe stellar variability by extrapolating from solar brightness variations. Our modelling shows that the solar paradigm is remarkably successful in explaining the stellar variability on the activity cycle timescale. For example, the model reproduces the observation that whereas the stars with a relatively low level of activity, become photometrically brighter as their activity level increases, more active stars display the opposite behaviour, becoming darker with rising activity level.

We simulate the solar variability as it would be measured out-of-ecliptic by Kepler and CoRoT and discuss the contributions of spots and faculae into the photometric stellar variability.

We show that modelling of stellar brightness variations can help to constrain the basic properties of stellar activity cycles, e.g. the latitudinal and size distributions of magnetic features on stellar surfaces, and pose challenges for dynamo models.

Rotation, differential rotation, and gyrochronology of active Kepler stars

Timo Reinhold[1], Laurent Gizon[2]

1: Georg-August-Universität Göttingen, Institut für Astrophysik (IAG)

2: Max-Planck-Institut für Sonnensystemforschung (MPS)

The high-precision photometry of the Kepler telescope has originated measurements of surface rotation periods for tens of thousands of stars, which can be used to infer stellar ages via gyrochronology. We present rotation periods of 18,500 stars, most of them consistent within 10% with the state-of-the-art rotation periods from McQuillan et al. (2014). Thereof, more than 12,000 stars show multiple significant peaks, which we interpret as differential rotation. Correlations of the relative and total shear with rotation period and effective temperature are in good agreement with theoretical predictions. Gyrochronology ages were derived for more than 17,500 stars, most of them with reasonable uncertainties dominated by period variations. We find that more than 95% of the stars in our sample are younger than the Sun. The age distribution shows a bimodality between 3200–4700 K, which vanishes towards hotter stars. Furthermore, the derived ages reveal an empirical activity-age relation with the variability range serving as stellar activity proxy.

1.12 Session: Stellar Dynamos (Theory) III

Friday, May 29, 11.10 am – 12.30 pm, chair: Stefan Dreizler

Theoretical limits on magnetic field strengths in low-mass stars

Matthew Browning[1], Gilles Chabrier[2], Maria Weber[1]

1: University of Exeter

2: Centre de Recherche Astrophysique de Lyon (CRAL)

Recent observations have suggested that some low-mass stars have larger radii than predicted by 1-D structure models. Some theoretical models have invoked very strong interior magnetic fields (of order 1 MG or more in some cases), and a consequent suppression of convective heat transport, as the cause of such large radii. Whether fields of such strength could in principle by generated by dynamo action in these objects is unclear, and I will address this question only glancingly. Instead, I will discuss whether such fields (however initially established) could remain in the interior of a low-mass object for a significant time, and whether they would have any other obvious signatures (apart from the claimed radius inflation). We have estimated timescales for the loss of strong fields by various mechanisms, and complementary constraints arising from the Ohmic dissipation of such fields, and find that these set practical limits on the fields that could be contained in fully convective stars. I will also briefly discuss how our simple analytical estimates compare to results from 3-D MHD simulations of stellar interiors.

Buoyancy Instabilities from Anisotropic Conduction in Stellar and Planetary Atmospheres

Felix Sainsbury-Martinez[1], Matthew Browning[1]

1: University of Exeter

In a low-collisionality plasma with a weak magnetic field, the convective instability requirement changes from an entropy dependence to a combination of the magnetic-field orientation and temperature gradient. In such cases, two instabilities are known to be available, the magnetothermal instability (MTI) and the heat-flux-driven buoyancy instability (HBI). Of particular interest to us is the HBI, which exhibits a number of non-linear effects – such as the restriction of vertical heat transport – that have previously been shown to play a key role in cool-core galaxy clusters, and which may prove to be important within smaller astrophysical bodies.

Here we give a brief overview of both instabilities before presenting initial results from our survey of the parameter regime in which the HBI might operate within smaller bodies; stellar and hot planetary atmospheres. We show that the key requirements for the HBI to operate are satisfied within portions of the outer regions of these atmospheres but that stabilization by magnetic tension presents a significant obstacle in both cases. Additionally, we give a brief overview of the 2D MHD simulations of the HBI that we have performed in order to investigate the evolution of the instability in various environments.

Understanding the equatorward migration of the Sun's magnetic field

Jörn Warnecke[1], Petri Käpylä[2,3], Maarit J. Käpylä, Axel Brandenburg[2,4]

1: Max Planck Institute for Solar System Research (MPS)

2: Nordic Institute for Theoretical Physics (Nordita)

3: Physics Department, Helsinki University

4: Department of Astronomy, Stockholm University

At the beginning of the cycle sunspots appear at high latitude, whereas at the end they appear close to the equator. This is associated with an underlying strong toroidal field which migrates equatorward. Since a few years this behavior has been reproduced in global convective dynamo simulations. I will present results from our simulations of global convective dynamos. All of these simulations produce cyclic and migrating mean magnetic fields. Through detailed comparisons, we show that the migration direction can be clearly explained by an alpha-Omega dynamo wave following the Parker-Yoshimura rule. This lead to the conclusion, that the equatorward migration in this and other work is due to a positive (negative) alpha-effect in the northern (southern) hemisphere and a negative radial gradient of rotation outside the inner tangent cylinder of these models. In the Sun the only region, where the rotation rate possesses a negative radial gradient, is in the near-surface shear layer. Furthermore, I will present results of transport coefficients: alpha, the turbulent pumping and the turbulent magnetic diffusivity obtained with the test-field method of dynamo simulations with equatorward and poleward migration. It turns out, that alpha can be indeed approximated with formulation related to kinetic helicity.

2 Abstracts: Posters

Systematic variations in sunspot group tilt angles for solar cycles 21-24

Emre Isik[1], Seda Isik[2,3]

1: Istanbul Kultur University

2: Kandilli Observatory and Earthquake Research Institute

3: Istanbul Technical University

We have measured sunspot group tilt angles using the digitised sunspot drawing archive of Kandilli Observatory in Istanbul between 1976 and 2015. The measurements and data analysis were carried out using a code we have developed for this purpose, allowing the user to select spot groups, spot positions and umbral areas, to calculate tilt angles. We have found that the cycle-averaged group tilt angle is anti-correlated with cycle strength (e.g., total spot area) confirming results of Dasi-Espuig et al. (2010). Further measurements of cycles 19 and 20 are currently being carried out.

Simulations of stochastic flux transport dynamos in Sun-like stars

Emre Isik[1]

1: Istanbul Kultur University

Using a newly developed stochastically driven nonlinear flux-transport dynamo model for Sun-like stars, we present simulations of activity cycles for Sun-like stars with rotation periods of 26, 10, and 2 days. The model takes into account the non-radial rise of flux tubes and the resulting tilt angles of bipolar regions (using thin flux tube simulations) for different stellar rotation rates.

The nature of grand solar minima and maxima during the Holocene epoch investigated by ^{10}Be and ^{14}C

Fadil Inceouglu[1], Rosaria Simoniello[2], M. Knudsen, Christoffer Karoff [1], Jesper Olsen [3], Sylvaine Turck-Chièze [4], B. Jacobsen

1: Aarhus University

2: Service d'Astrophysique (SAp), CEA

3: AMS ^{14}C Dating Centre Aarhus

4: CEA/DSM/IRFU

Sunspot observations since 1610 have revealed that the solar activity varies cyclically with a period of roughly 11 years, which is modulated on longer time-scales as exhibited by grand solar minima and maxima. These periods are believed to represent a special state of the solar dynamo and they pose a challenge for solar dynamo models.
Information on solar variations prior to 1610 relies on past production rates of cosmogenic nuclides, such as ^{10}Be and ^{14}C. Their production rates are inversely correlated with solar magnetic activity and the geomagnetic field intensity due to the non-linear shielding effect of the solar magnetic field and the geomagnetic dipole field.
In this study, we use ^{14}C and ^{10}Be records to study the occurrences of grand minima and grand maxima. Based on this approach, we found that during the period from 1650 AD back to 6600 BC, the Sun experienced 32 grand minima and 21 grand maxima periods. We also suggested that the occurrence and nature of grand minima and maxima do not reflect purely random processes without a memory. Furthermore, wavelet analyses reveal that the 22-year Hale cycle tends to weaken during grand minimum episodes, whereas it's more pronounced during grand maximum periods. This behavior can be linked to variations of the meridional circulation in the Sun. Such observations may serve as an important guide for solar dynamo models.

The time variation of the near-surface shear layer of the Sun

Atefeh Barekat[1], Jesper Schou[1], Laurent Gizon[1]

1: Max-Planck-Institut für Sonnensystemforschung (MPS)

Providing quantitative measurements of the differential rotation of the Sun is important for dynamo theory. Following our previous work (Barekat et al 2014), we measure the logarithmic radial gradient of the angular velocity (dlnOmega/dlnr) of the near surface shear layer of the Sun using the same method, but different data sets. We use 15 years (1996-2011) splitting data obtained from 360-days time series of medium-l program MDI on board of SOHO and 5 years (2010-2015) HMI data on board of SDO. We obtained similar, but not identical result as of our previous work where dlnOmega/dlnr stays close to -1 from the equator to 60 degree latitude. We also show that dlnOmega/dlnr is not constant over time and shows similar pattern as the torsional oscillation.

Linear simulations of acoustic waves in spotted stars

Emanuele Papini[1], Aaron Birch [1], Laurent Gizon [1,2]

1: Max-Planck-Institut für Sonnensystemforschung (MPS)

2: Institut für Astrophysik, Georg-August-Universität Göttingen

Stellar acoustic oscillations are affected by magnetic activity, however it is unclear how starspots contribute to these changes. In this context we investigate the effects of a model starspot on the low-degree modes of oscillation, by means of 3D linear time-domain simulations performed using the GLASS code. We model the starspot as a 3D change in the sound-speed stratification with respect to a convectively stabilized solar Model S. We show that for a polar spot configuration the interaction of the axisymmetric modes with the starspot is strongly nonlinear. Preliminary results show that including rotation complicates the scenario by causing an additional splitting in the mode frequencies which adds to the asymmetric splittings caused by the spot. This may lead to misidentification of modes in observed acoustic power spectra.

Internal and surface rotation of six Sun-like stars

Martin Nielsen[1], Hannah Schunker[2], Laurent Gizon [2], Jesper Schou [2]

1: Institute for Astrophysics Goettingen (IAG)

2: Max Planck Institute for Solar System Research (MPS)

Stellar rotation can be independently measured using both starspot rotation signals and asteroseismology. Asteroseismology is sensitive to the interior rotation of the star, whereas starspot rotation is thought to be closer to the surface rotation rate as is the case for the Sun. Here we have identified six high signal-to-noise main-sequence Sun-like stars in the Kepler field, which all have visible signs of rotational splitting of their p-mode frequencies. Five of these stars also have detectable signals from starspot rotation. The rotation rates for each star from both starspots and asteroseismology are consistent within the uncertainties. Asteroseismology also offers the prospect of constraining differential rotation in Sun-like stars. We are able to make independent measurements of rotational splittings of 8 radial orders for each star. For all six stars, the measured splittings are consistent with uniform rotation, allowing us to exclude large radial differential rotation and place constraints on the internal rotation of Sun-like stars.

Measurement of turbulent quantities at the Sun's surface: velocity, vorticity and their correlations from observations

Damien Fournier[1], Jan Langfellner [2], Laurent Gizon [2,3]

1: Institut für Numerische und Angewandte Mathematik, Georg-August-Universität Göttingen

2: Institut für Astrophysik, Georg-August-Universität Göttingen

3: Max-Planck-Institut für Sonnensystemforschung (MPS)

As a full model of stellar convection is still out of reach, analysis and interpretation of seismic data are currently out best hope to understand Solar dynamo. Dopplergrams containing the line-of-sight velocity are obtained every 45 s by the Solar Dynamics Observatory (SDO). An independent measurement can be obtained by tracking granules at the Sun's surface (Local Correlation Tracking on intensity images). Here, we compare the results obtained by these two techniques in order to obtain quantities describing turbulence at the Sun's surface. We show in particular measurements of the horizontal Reynolds stress and of the two-point velocity correlation but also the vertical component of the flow vorticity and its correlation with the divergence of the flow. All these quantities exhibit a latitudinal dependance that will be analyzed using a model of rotating anisotropic turbulence.

Helioseismology of subsurface flows

Zelia Ferret[1], Laurent Gizon[1,2], Michael Leguebe [1], Damien Fournier [3], Jan Langfeller

1: Max-Planck-Institut für Sonnensystemforschung

2: Institut für Astrophysik, Georg-August-Universität Göttingen

3: Institut für Numerische und Angewandte Mathematik, Georg-August-Universität Göttingen

Though supergranulation is easily observed on the solar surface, its subsurface properties are still unknown. To get a better understanding of the subsurface flows, we consider several parametrizations of the flows under the condition of mass conservation. Using the Montjoie forward solver, we infer the effect of different flow topologies on the propagation of acoustic wavepackets in the solar interior. The goal is to get a better understanding of the sensivity of helioseismic travel times to various models of supergranulation.

Dynamo models for magnetic field generation in Uranus and Neptune

Andrea Bossmann[1], Johannes Wicht [1], Thomas Gastine [1], Ulrich Christensen [1]

1: Max Planck Institute for Solar System Research (MPS)

The magnetic fields of the ice giants are multipolar and non-axisymmetric. Voyager-II-data and HST aurorae-observations suggest magnetic power spectra with similar power in the first three spherical harmonic degrees and a peak in the order m=1. Multipolar, non-axisymmetric fields can be modeled with several different approaches including a high density stratification in the dynamo region, strongly turbulent convection, a dynamo generated by fast zonal jets and a geometrical setup with a deep stably stratified fluid layer below the dynamo region. Earlier studies with this geometry found multipolar fields and in a few cases reproduced the peak in the magnetic power spectra at order m=1 (Stanley and Bloxham, 2006). Here we explore the robustness of the multipolarity (similar power for l=1,2,3) and the m=1-peak for a range of parameters and geometrical setups using 3D numerical dynamo models. We compare our results to internal structure models of the ice giants in order to constrain the parameters and geometrical setups that are in accordance with the magnetic field observations.

Surface flux transport simulations: Effect of inflows around active regions and random velocities on the evolution of the Sun's large scale magnetic field

David Martin Belda[1], Robert Cameron [2]

1: Max Planck Institute for Solar System Research

Aims. We aim to determine the efect of converging flows towards active regions on the evolution of a bipolar magnetic region, and to investigate the role of these inflows in the generation of poloidal flux. We also discuss wether the flux dispersal due to turbulent flows is well described as a diffusion process. Methods. We have developed a simple surface flux transport model based on point-like magnetic concentrations. We have run simulations of the evolution of a bipolar magnetic region with and without inflows in order to compare the results. To test the diffusion approximation simulations of random walk dispersal of magnetic features at two dierent scales (corresponding to granules and supergranules) have been run. Results. We find that the inflows enhance flux cancellation, but at the same time affect the latitudinal separation of the polarities of the bipolar region. In most of the cases these two effects combine to reduce the amount of net flux arriving to the poles, but when the tilt angle of the BMR is close to zero the effect is the opposite. We also confirm the validity of the diffusion approximation to describe flux dispersal in large scales.

Fundamentals of Acoustic Holography

Dan Yang[1], Laurent Gizon[1,2]

1: Max-Planck-Institut für Sonnensystemforschung

2: Institut für Astrophysik, Georg-August-Universität Göttingen

We review the basic principles of acoustic holography and current applications to the Sun. In particular, we discuss the Porter-Bojarski hologram for the Helmholtz equation, which relates the wavefield recorded on a bounding surface to sources and scatterers in 3D space. This is a promising concept that may be generalized to reconstruct the wavefield in the solar interior.

Progress in Computational Helioseismology

Chris Hanson[1], Damien Fournier[2], Michael Leguebe [1], Laurent Gizon [1,3]

1: Max-Planck-Institut für Sonnensystemforschung (MPS)

2: Institut für Numerische und Angewandte Mathematik

3: Institut für Astrophysik

Solar acoustic waves are continuously and stochastically excited by turbulent convective motion within the solar interior. Our goal is to reconstruct the 3D interior of the sun using this wavefield by computing the cross covariance between two points on the solar surface. We utilize the finite element solver Montjoie to achieve this goal, and in a first step examine a few simplified forward problems. Results thus far include a solar like power spectrum, accurate travel time calculations and the determination of travel time sensitivity kernels that will be used in future inversion problems based on observational data.

Solar Spectroscopy with the Fourier Transform Facility in Göttingen

Ansgar Reiners[1]

1: Institute for Astrophysics Goettingen

At the Institut für Astrophysik Göttingen (IAG), we are operating a Vacuum Vertical Telescope together with a Fourier Transform Spectrograph to obtain high-precision disk-averaged and spatially resolved spectroscopy of the solar surface. A first product is a high-precision atlas of the solar spectrum in the range 0.4–2.3mum at a resolving power of R 1,000,000. We are observing the disk-integrated sun monitoring short-cadence radial velocity variations that are caused by motions of the turbulent plasma and its suppression by magnetic regions. The observations help to understand convective flow patterns and the role of turbulence in the search for extrasolar planets.

Evolution of internal magnetic field in solar-like stars during the PMS phase

Constance Emeriau-Viard[1], Allan Sacha Brun[1], Nicholas Featherstone

1: Astrophysique Interactions Multi-échelles (AIM)

We present our study of generation and evolution of magnetic fields in solar-like stars during their PMS phase. At the beginning of the PMS, stars go through a highly turbulent convection phase. During this phase, dynamo action generates an intense magnetic field in the star. The question is to know how the nature of the dynamo regime and how that magnetic field further develop as the star evolves through PMS and arrives on the ZAMS. To answer that question, we have developed numerical models with ASH code that represent a solar-like star at different stages of the PMS. In our youngest model, both convection and differential rotation yield dynamo action that efficiently generate a global magnetic field, with the magnetic energy reaching of the order of 10 to 50% of the total kinetic energy. We are currently working on following models to see the evolution of internal magnetic field in stars as their internal structure evolve and their convective envelop becomes thinner.

Towards magnetic sounding of the Earth's core by an adjoint method II

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We apply a variational data assimilation framework to an inertia-free magnetohydrodynamic (MHD) model of the core (Glatzmaier and Roberts, 1995) in which the dominant balance is between Coriolis forces, pressure, Lorentz forces and buoyancy; we have also added a small amount of viscosity to this system. We chose to study the MHD system driven by a static temperature anomaly to mimic the actual inner working of Earth's dynamo system, avoiding at this stage the further complication of solving for the time dependent temperature field. We use synthetic observations derived from evolving a geophysically-reasonable magnetic field profile as the initial condition of our MHD system. Observations of radial magnetic field or together with the information of flow, are assimilated on several different 2D surfaces. Based on our study, we also propose several different strategies for accurately determining the initial condition and thus the entire trajectory of Earth's geodynamo system.

Torsional Oscillations propagation and reflections in rapidly rotating spherical bodies

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The magnetohydrodynamics of stars and planetary cores is usually dominated by the overwhelming importance of rotation compared to other forces. In these conditions the fluid motions are characterized by invariance along the direction parallel to the rotation axis (vertical direction). In the presence of a background magnetic field magnetohydrodynamic oscillations whose restoring force is provided by the magnetic tension can be triggered. Of particular interest are the Torsional Oscillations (TOs), azimuthal perturbation of the fluid that are axisymmetric and invariant along the vertical direction whose periods depends solely on the intensity of the magnetic field component aligned with the radial direction of propagation. As the detection of the fundamental period could constrain the magnetic field intensity in the Earth's outer core, and therefore on geodynamo models results, there is a long history of attempted detection of TOs from geomagnetic data. There is however a fundamental lack of knowledge concerning the propagation and reflection properties of these waves, as observational studies suggests behaviors that are different from theoretical expectations. Through numerical simulation and analytical techniques we will analyze temporal evolution of TOs in spherical geometry, with particular attention on the reflection at the equator and the pseudo-reflection at the rotation axis.

Numerical simulation of the dynamo effect in a precessing cube

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Numeric simulations of rotating flows are often limited by effects in the boundary layer, which need a very high grid resolution. We investigate the ability of precession driven flows to amplify magnetic fields due to the dynamo effect in a cubic geometry. For this we use free-slip boundary conditions instead of more problematic no-slip conditions while calculating a DNS system on gpu-computing machines. This will help to provide further insights into dynamics of rotating fluids generally and into the dynamo effect in planets specifically.

Hysteresis between distinct modes of turbulent dynamos

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We perform three-dimensional simulations of large-scale dynamos in a shearing box with helically forced turbulence. As initial condition, we either take a weak random magnetic field or we start from a snapshot of an earlier simulation. Two quasi-stable states are found to coexist in a certain range of parameters close to onset of the large-scale dynamo. The simulations converge to one of these states in dependence on the initial conditions. When either the fractional helicity or the magnetic Prandtl number is increased between successive runs above the critical value for onset of the dynamo, the field strength jumps to a finite value. However, when the fractional helicity or the magnetic Prandtl number is then decreased again, the field strength stays at a similar value (strong field branch) even below the original onset. We also observe intermittent decaying phases away from the strong field branch close to the point where large-scale dynamo action is just possible. The dynamo hysteresis seen previously in mean-field models is thus reproduced by 3D simulations. Its possible relation to distinct modes of solar activity such as grand minima is discussed.

Optimization of the Magnetic Dynamo in a Cube

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A subcategory of Earth's liquid core models is called the kinematic dynamo. The magnetic Reynolds number (Rm) is a characteristic parameter in kinematic dynamos, which is the ratio of magnetic advection to magnetic diffusion. Ashley Willis (2012) used a Lagrangian optimization method to find the most efficient dynamo in a periodic box, i.e, find the critical Rm that can just create a dynamo. We apply the same technique to simultaneously look for the optimal flow field and initial conditions for the magnetic field for different Rm. The fields evolve from a given energy over a chosen time window T. When the instantaneous growth rate at T is zero after a transient period, we have found the most efficient dynamo. However, a realistic dynamo model cannot have a periodic flow, so we use a confined flow inside the cube. We also use four combinations of perfectly conducting and pseudo-vacuum magnetic boundaries as Krstulovic et al. (2011). Starting with random noise, the optimal solution is found after many iterations. Subsequent analysis for the optimal fields will be presented. We plan to apply the same method to spherical dynamo models and find the critical Rm for different types of flows.

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