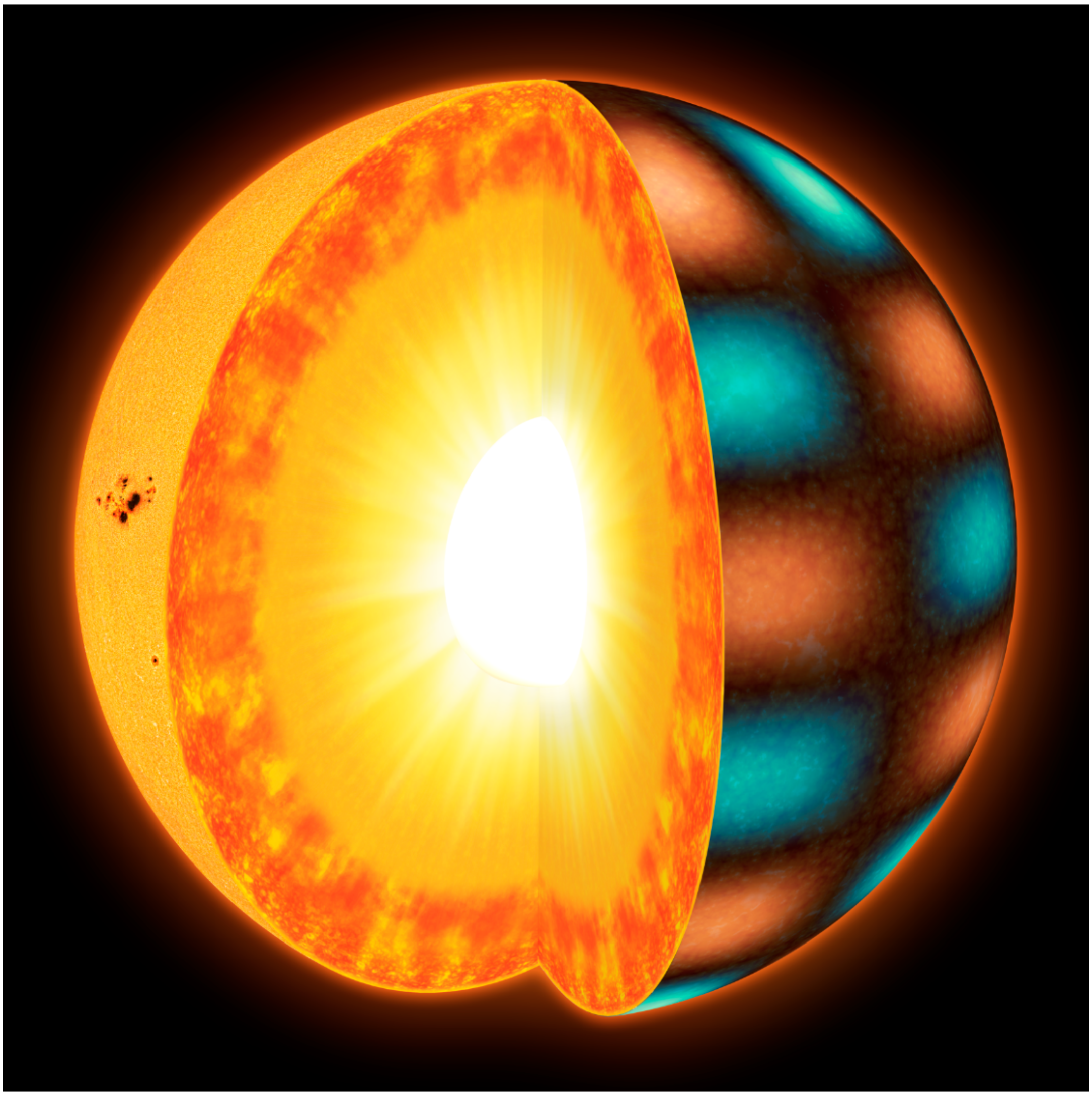
HELAS VI / SOHO 28 / SPACEINN
Helioseismology and Applications

Scientific Programme and Abstracts



1-5 September 2014
Göttingen, Germany

Hosted by the Max Planck Institute for Solar System Research

Scientific Programme and Abstracts
edited by M. Ammler-von Eiff & L. Gizon

Organizing Committee:

Matthias Ammler-von Eiff (MPI for Solar System Research, Germany)
Aaron C. Birch (MPI for Solar System Research, Germany)
Sabine Deutsch (MPI for Solar System Research, Germany)
Bernhard Fleck (European Space Agency)
Laurent Gizon (Chair, MPI for Solar System Research / University of Göttingen, Germany)
Frank Hill (National Solar Observatory, U.S.A.)
Jan Langfellner (University of Göttingen, Germany)
Kaori Nagashima (MPI for Solar System Research, Germany)
Markus Roth (Kiepenheuer-Institut für Sonnenphysik, Germany)
Hannah Schunker (MPI for Solar System Research, Germany)
Michael J. Thompson (High Altitude Observatory, U.S.A.)

Göttingen, 1 September 2014

Contents

Scientific programme

Ongoing and Future Projects

Monday morning (Sept. 1) Chair: Hannah Schunker

9:00 - 9:10	Laurent Gizon	Welcome
9:10 - 9:30	Phil Scherrer	SDO, HMI and JSOC progress and status
9:30 - 9:50	Richard Bogart	HMI local helioseismology data: status and prospects
9:50 - 10:10	Frank Hill	GONG status and results
10:10 - 10:40	*Coffee and Posters*	
10:40 - 11:00	Guy R. Davies	The Sun as a star: insights from BiSON, *Kepler* and CoRoT
11:00 - 11:20	Björn Löptien	Helioseismology with Solar Orbiter
11:20 - 11:40	Sylvaine Turck-Chièze	The OPAC International Consortium
11:40 - 12:00	Markus Roth	SPRING: A new ground-based network for synoptic solar observations
12:00 - 14:00	*Group photo and lunch*	

Convection and Dynamics

Monday afternoon (Sept. 1) Chair: Mike Thompson

14:00 - 14:20	Atefeh Barekat	Radial gradient of the near-surface shear layer of the Sun
14:20 - 14:40	Jesper Schou	Interaction of waves with solar convection
14:40 - 15:00	Shravan M. Hanasoge	Imaging convection in the solar interior
15:00 - 15:20	Michal Švanda	Recent results on surface flow fields from timeâdistance helioseismology
15:20 - 15:50	*Coffee and Posters*	
15:50 - 16:10	Jan Langfellner	Spatially resolved vorticity in supergranulation with helioseismology
16:10 - 16:30	Damien Fournier	Inversion of the two-point velocity correlations on the Sun's surface
16:30 - 16:50	Günther Rüdiger	The existence of the Λ effect in the solar convection zone as indicated by SDO observations

Active Regions

Tuesday morning (Sept. 2) Chair: Markus Roth

9:00	- 9:20	Hannah Schunker	Catalogue of emerging active regions observed by HMI (May 2010 – Dec 2012)
9:20	- 9:40	Aaron C. Birch	Near-surface flows associated with evolving active regions
9:40	- 10:00	Sushanta C. Tripathy	Horizontal flows in active regions from multi-spectral observations of SDO
10:00	- 10:40	*Coffee and Posters*	
10:40	- 11:00	Paul Cally	Can the seismology of active regions be decoupled from the chromosphere?
11:00	- 11:20	Axel Brandenburg	F-mode signal from localized magnetic flux concentrations
11:20	- 11:40	Hamed Moradi	What can we learn from directional time-distance probing of solar magnetic regions?
11:40	- 12:00	Sergiy Shelyag	Spectropolarimetric signatures of mode conversion in simulated sunspots
12:00	- 14:00	*Lunch*	

The Solar Cycle

Tuesday afternoon (Sept. 2) Chair: Paul Cally

14:00	- 14:20	Anne-Marie Broomhall	Insights into the solar cycle from global helioseismology
14:20	- 14:40	Timo Reinhold	Activity, rotation and stellar ages using *Kepler*
14:40	- 15:00	Robert H. Cameron	Observational constraints on the solar dynamo
15:00	- 15:20	Ed Rhodes	Probing the solar interior on multiple timescales using global helioseismology
15:20	- 15:50	*Coffee and Posters*	
15:50	- 16:10	Dean-Yi Chou	Magnetic fields at the base of solar convection zone
16:10	- 16:30	H.M. Antia	Solar rotation during cycles 23 and 24
16:30	- 16:50	Jörn Warnecke	Simulations modeling global turbulent convective dynamos of the Sun with and without coronal envelope

The Legacy of Irene González Hernández

Wednesday morning (Sept. 3) Chair: Frank Hill

9:00	-	9:20	Frank Hill	Farside maps and space weather forecasting
9:20	-	9:40	Jesús Patrón	Pioneering work on ring diagram analysis with Irene González Hernández
9:40	-	10:00	Charles Lindsey	Seismic mapping of the Sun's far hemisphere
10:00	-	10:40	*Coffee and Posters*	
10:40	-	11:00	Junwei Zhao	Time-distance farside imaging using SDO/HMI data
11:00	-	11:20	Douglas Braun	Local helioseismic investigation of emerging active regions
11:20	-	11:40	Rudolf Komm	Solar-cycle variation of subsurface flows derived from GONG and SDO/HMI
11:40	-	12:00	Rachel Howe	Persistent near-surface flow structures from ring-diagram analysis of GONG and HMI data
12:00	-		*Lunch*	

SPACEINN Workshop: Systematics

Thursday morning (Sept. 4) Chair: Kaori Nagashima

9:00	-	9:30	Sylvain Korzennik	What can we learn about the solar subsurface large scale flows from accurate high-degree modes frequencies?
9:30	-	10:00	Thomas L. Duvall Jr.	A new time-distance measurement of meridional circulation that is not susceptible to center-to-limb effects
10:00	-	10:40	*Coffee and Posters*	
10:40	-	11:00	Timothy Larson	Medium-degree analysis of Mount Wilson data
11:00	-	11:20	Kaori Nagashima	SDO/HMI multi-height velocity measurements
11:20	-	11:40	Vincent Böning	Extension to spherical geometry: sensitivity kernels for flows in time-distance helioseismology
11:40	-	12:00	Ariane Schad	Distortion of global mode eigenfunctions
12:00	-	14:00	*Lunch*	

Solar Structure / Asteroseismology

Thursday afternoon (Sept. 4) Chair: Sylvaine Turck-Chièze

14:00	-	14:20	M. Cristina Rabello Soares	Solar structure as seen by high-degree modes
14:20	-	14:40	Sergei Vorontsov	Seismic diagnostics of the equation of state and element abundances in the solar envelope
14:40	-	15:00	Sergey Ayukov	On the possibility of constructing solar model with helioseismic convection zone
15:00	-	15:20	Vladimir Baturin	Evidence of early solar evolution in the tachocline and overshooting region below the present convective zone
15:20	-	15:50	*Coffee and Posters*	
15:50	-	16:10	Rafael A. Garcia	Low-degree and low-order global seismology of the Sun and stars
16:10	-	16:30	Takashi Sekii	Rotation of KIC 11145123
16:30	-	16:50	Warrick Ball	New parametrizations of near-surface effects in solar-like oscillators

Ways Forward

Friday morning (Sept. 5) Chair: Bernhard Fleck

9:00	-	9:20	Katepalli R. Sreenivasan	Turbulent convection in the laboratory
9:20	-	9:40	Hannah Schunker	Sunspot seismology
9:40	-	10:00	Manfred Küker	Modeling solar dynamics
10:00	-	10:40	*Coffee and Posters*	
10:40	-	11:00	Laurent Gizon	Trends in theoretical helioseismology
11:00	-	11:20	Jesper Schou	Future of observational helioseismology
11:20	-	11:40	Thierry Appourchaux	Prospects for asteroseismology of solar-type stars
11:40	-	12:00	Michael J. Thompson	Conference summary
12:00	-		*Lunch*	

Posters

On display every day **Posters**

Jishnu Bhattacharya	Modeling surface layer induced corrections in the solar seismic spectrum through spatial homogenization
Dean-Yi Chou	Probing magnetic fields in solar interiors: solar-cycle variations of meridional flows
Bernhard Fleck	The MOTH II Experiment
Vigeesh Gangadharan	A Fourier-Legendre analysis module for the SDO Data Analysis Pipeline
Kolja Glogowski	Python bindings for NetDRMS
Frank Hill	Properties of p-mode oscillations observed in strong Hα flares
Rachel Howe	Helioseismology at different wavelengths using HMI and AIA
Rachel Howe	The torsional oscillation and the timing of the solar cycle
Stathis Ilonidis	Using SDO/HMI observations to detect pre-emergence signatures of large active regions
René Kiefer	Magnetic field and solar oscillations
Rudolf Komm	Current and kinetic helicity of long-lived activity complexes
Sylvain G. Korzennik	Fitting resolved modes using GONG, MDI and HMI observations
John Leibacher	Helioseismic diagnostics of solar flares
Björn Löptien	Image compression in local helioseismology
Emanuele Papini	Simulating acoustic waves in spotted stars
Damien Przybylski	Oscillatory and radiative properties of a sunspot model
Carlos Rijs	Photospheric fast wave refraction as a mechanism for the acoustic halo
Markus Roth	Exploitation of space data for innovative helio- and asteroseismology (SPACEINN)
Jesper Schou	Earth-Affecting Solar Causes Observatory (EASCO): An L5 Mission concept for solar physics and space weather
Hannah Schunker	Emerging active regions observed by SDO/HMI for helioseismology
Nishant K. Singh	Properties of p and f modes in hydromagnetic turbulence
Sushanta C. Tripathy	Cross-spectral fitting of GONG and HMI oscillation data
Aneta Wisniewska	Investigation of solar oscillations with the HELLRIDE instrument
Junwei Zhao	Fast-moving waves propagating from penumbra to outside of sunspots in the photosphere

Abstracts

Abstracts of talks and posters are ordered alphabetically by the first author. Only the affiliation of the presenter is given.

Solar rotation during cycles 23 and 24

H. M. Antia*
*Tata Institute of Fundamental Research, Mumbai, India
(antia@tifr.res.in)

Helioseismic data during the last 19 years covering entire solar cycle 23 and the rising phase of solar cycle 24 have been used to study the rotation rate and its variation during the solar cycle. The temporally varying component of the rotation rate and its gradients shows the well known bands of faster and slower than average value, which correlate with the bands in the butterfly diagram for solar activity. With the data covering two minima in solar activity it is also possible to study the variation between the two solar cycles and the behaviour during the peculiar minimum between solar cycles 23 and 24.

Prospects for asteroseismology of solar-type stars

Thierry Appourchaux*
*Institut d'Astrophysique Spatiale, Orsay, France
(Thierry.Appourchaux@ias.u-psud.fr)

With the advent of Kepler, one could wonder what PLATO will bring to asteroseismology in more than 10 years from now. I will review what I believe has been left off the board starting with binary stars, clusters, mode physics, internal rotation and all that in the grotto ! I will finish with a perspective view going beyond my retirement date.

On the possibility of constructing solar model with helioseismic convection zone

Sergey Ayukov*

*Sternberg Astronomical Institute, Moscow State University, Russia
(asv@sai.msu.ru)

According recent helioseismic calibrations (MNRAS v.430, No 3, p.1636, 2013) adiabatic compressibility in solar convection zone conforms to models with low heavy element abundance (Z). This result relies on calibrations of models with two independent EOS calculations (OPAL and SAHA-S) which agree on low Z content. These helioseismic calibrations also give helium abundance in convection zone and convection zone mass parameter M75=0.9822 (M75 = Mr/M (r/R=0.75)). Standard solar model (with high Z content) conforms to helium abundance but have M75=0.9826. We attempt to construct solar models with proper M75 in envelope while conforming to helioseismic sound speed profile below the convection zone. The question of low Z in convection zone remains open.

New parametrizations of near-surface effects in solar-like oscillators

Warrick Ball*

*Institut für Astrophysik, Georg-August-Universität Göttingen, Germany
(wball@astro.physik.uni-goettingen.de)

Space-based observations of solar-like oscillations present an opportunity to constrain stellar models using individual mode frequencies, but current stellar models are inaccurate near the surface, which induces a systematic difference between models and observations. These surface effects must be corrected to reduce the systematic error on underlying stellar model parameters. I will present two new parametrizations of the surface effect based on formulae by Gough (1990), and show that these parametrizations accurately correct model frequencies for two calibrated solar models. I then show the results of using the corrections to fit the planet-hosting CoRoT target HD52265 and compare our results with the widely-used correction proposed by Kjeldsen et al. (2008). All the corrections yield similar underlying model parameters, but the new corrections give a significantly better fit.

Radial gradient of the near-surface shear layer of the Sun

Atefeh Barekat*
*MPI für Sonnensystemforschung, Göttingen, Germany (barekat@mps.mpg.de)

Precise measurements by the Michelson Doppler Imager (MDI) and Heliosismic Magnetic Imager (HMI) in the last two decades have improved our understanding of the internal rotation rate of the Sun greatly.

Using f-modes with $117 \leq l \leq 300$ from MDI, Corbard & Thompson (2002) showed that the logarithmic radial gradient of the rotation rate near the solar surface stays close to -1 from the equator to 30° latitude and appeared to change sign at 50° latitude. However, they also suspected that there were large systematic errors in the old MDI data.

We extend this study using a different method and 15 years of reprocessed MDI data from 1996 to 2010 and four years HMI data from 2010 to 2014. We find that the logarithmic radial gradient of the rotation rate stays close to -1 from the equator to 60° latitude and stays negative to 75° latitude. There is some discrepancy between the results obtained from MDI and HMI at high latitude and further analysis shows that the results obtain for latitude ≥ 65 are not reliable. We confirm the suspicion of Corbard & Thompson that systematic errors in the old MDI data led to the change in sign of the gradient at around 50° latitude.

Evidence of early solar evolution in the tachocline and overshooting region below the present convective zone

Vladimir Baturin*
*Sternberg State Astronomical Institute, Moscow State University, Russia (vab@sai.msu.ru)

Based on the helioseismic inversion of the buoyancy frequency profile just below of the convective zone, we are looking for traces from the early (ZAMS) convective boundary in the hydrogen gradient profile. Specific features of the gradient profile give an estimation of depth and structure of overshooting region and a receipt for improving of the sound speed in the model.

Modeling surface layer induced corrections in the solar seismic spectrum through spatial homogenization

Jishnu Bhattacharya*

*Tata Institute of Fundamental Research, Mumbai, India
(jishnu.bhattacharya@tifr.res.in)

In this paper we study the effect of small scale horizontal convective flows on large wavelength acoustic waves. The flow field acts as a scatterer which alters the dispersion relation of the wave. We derive an effective homogenized perturbative wave equation using the method of multiple scales, which incorporates the effect of the flow in the wave equation till the first order. To test our equation we choose a periodic array of vortical flows and numerically compute the dispersion relation corresponding to the exact and the homogenized solution. We show that in the limit $cell\ size \ll \lambda$ the homogenized dispersion relation matches the exact one to within one part in thousand. Both the relations predict a frequency which undershoots the acoustic $\omega = ck$ by a few μHz ; the difference results from a modification in the wave propagation speed induced by the flows. The homogenized equation can be extended from periodic to random flows, thereby having broad implications in modelling surface term corrections corresponding to granulation on the sun.

Near-surface flows associated with evolving active regions

Aaron Birch*

*MPI für Sonnensystemforschung, Göttingen, Germany (birch@mps.mpg.de)

We have developed a catalog of about 100 emerging active regions. We have applied helioseismic holography to these regions and found spatially complex and time-evolving near-surface flows associated with these active regions in their post-emergence phase. We see near-surface flows associated with the East-West separation of the two polarities of emerging magnetic flux and also a non-axisymmetric and time-evolving near-surface converging flow.

Extension to spherical geometry: sensitivity kernels for flows in time-distance helioseismology

Vincent Böning*

*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany (vboening@kis.uni-freiburg.de)

We extend an existing Born approximation model for calculating the linear sensitivity of helioseismic travel-times to flows from plane-parallel to spherical geometry. This extension is necessary especially for dealing with deep flows. Furthermore, we present first results for the sensitivity kernels and validate our model with the help of artificial helioseismic data for a standard meridional flow pattern from Hartlep et al. (2013, ApJ).

HMI local helioseismology data: status and prospects

Richard Bogart*

*Stanford University, Stanford, CA, USA (rick@sun.stanford.edu)

We will discuss the local helioseismology data products from the HMI analysis pipelines (ring-diagrams, time-distance, and farside imaging), with emphasis on known problems in their interpretation and prospects for improvement.

F-mode signal from localized magnetic flux concentrations

Axel Brandenburg*

*Nordita, Stockholm, Sweden (brandenb@nordita.org)

I will talk about recent attempts to construct diagnostic k-omega diagrams from turbulence simulations showing self-consistent magnetic spot formation. The turbulence in these simulations is driven by a forcing function rather than by convection, which has the advantage that the length scale of the turbulent eddies can be smaller than the local scale height and thereby mimic aspects of fully developed turbulence that cannot currently be assessed in convection simulations.

Spontaneous magnetic flux concentrations and spots are produced by downflows that are a consequence of the magnetic field itself. (In reality, convection will also contribute, but our model allows us to isolate the purely magnetic effects from convection.) We find a noticeable increase of the f-mode frequency for horizontal fields and a frequency decrease at large wavenumbers for vertical fields. When the magnetic field is nonuniform, we find a fanning out of the f-mode such that it has a top-hat profile. I will also talk about attempts to assess the effects of turbulence and magnetic fields in the simulations using ray tracing experiments.

References:
Singh, N. K., Brandenburg, A., Rheinhardt, M.: arXiv:1407.0356
Singh, N. K., Brandenburg, A., Chitre, S. M., Rheinhardt, M.: arXiv:1404.3246

Local helioseismic investigation of emerging active regions

Douglas Braun*

*NorthWest Research Associates, Boulder, CO, USA (dbraun@cora.nwra.com)

Attempts to seismically probe emerging sunspots and magnetic regions date back nearly two decades. However, case studies of events have often lead to disparate or controversial results and are plagued by low signal-to-noise levels. Recent surveys of the subsurface properties of emerging regions have been carried out with datasets obtainable with the GONG network and the HMI instrument on the NASA Solar Dynamics Observatory. Surveys offer the potential to detect weak signals through ensemble averaging and to study the statistical properties of the emergence process. The talk will address how the combination of new survey data with state-of-the-art MHD computations of emerging flux allows us to explore the physics of active region emergence. Collaborators on the current project highlighted in this talk include Aaron Birch, Hannah Schunker (MPS), Matthias Rempel (NCAR), and Ashley Crouch (NWRA). Irene González Hernández played a critical role in getting the first, GONG-based, survey off to a successful start and this presentation is dedicated to her memory. This work is supported by the NASA HSR and HGI programs.

Insights into the solar cycle from global helioseismology

Anne-Marie Broomhall*

*University of Warwick, United Kingdom (a-m.broomhall@warwick.ac.uk)

It is well known that the properties of the Sun's global acoustic oscillations (p modes), such as their frequencies, vary with the Sun's magnetic activity cycle. Consequently, the observed variations in the properties of p modes are often compared with other well-known proxies of the Sun's magnetic activity, such as the 10.7cm radio flux and the sunspot number. In light of the recent work of Livingston and Penn that appears to show a deviation since the turn of the century between the 10.7cm flux and the sunspot number we present an up-to-date analysis of the relationships observed between the properties of global p modes and various proxies of the Sun's activity, including the 10.7cm flux and the sunspot number.

Can the seismology of active regions be decoupled from the chromosphere?

Paul Cally*, Hamed Moradi, Shelley Hansen

*Monash University, Clayton, Victoria, Australia (paul.cally@monash.edu)

Strong magnetic fields in active regions create openings in the solar surface that allow seismic waves normally restricted to the interior to penetrate into the chromosphere and beyond. However, a complex array of mode conversion and reflection causes some part of these waves to return to the surface. Recent modelling and simulations at Monash have begun to quantify the effect this has on Time-Distance "travel times", and it can be considerable. I will also report on the role of the Transition Region, and the implications for AlfvÃn wave generation.

Observational constraints on the solar dynamo

Robert H. Cameron*
*MPI für Sonnensystemforschung, Göttingen, Germany (cameron@mps.mpg.de)

Using a variety of different observations we infer several key aspects of the solar dynamo, including both the random and systematic variation in the level of activity from one 11 year cycle to the next.

Magnetic fields at the base of solar convection zone

Dean-Yi Chou*
*National Tsing Hua University, Taiwan (chou@phys.nthu.edu.tw)

We show the observational evidence of magnetic fields at the base of convection zone (BCZ) with solar-cycle variations of meridional flows. Using solar-cycle variations of meridional flows to probe the magnetic fields at the BCZ has an advantage over using solar-cycle variations of mode frequency or mean travel time. Here using the SOHO data, we are able to measure the latitudinal distribution of meridional flow signals in the solar interior down to 0.54R over 15 years. The surface magnetic effects and center-to-limb effects are removed. The difference between solar maximum and minimum suggests the presence of magnetic fields around the BCZ, and places a lower limit of 2000 gauss for the field strength at the BCZ.

The Sun as a star: insights from BiSON, *Kepler* and CoRoT

Guy R. Davies*
*University of Birmingham, United Kingdom (davies@bison.ph.bham.ac.uk, grd349@gmail.com)

We present results on an exceptional asteroseimic target. This G2V target, with an age of around 4.5 Gyr, has been observed near-continuously since the late

1980's using a variety of ground- and space-based instruments. These unique data sets, in both quality and quantity, allow us to grasp a deep understanding of Sun-like stars.

Here we narrow our focus to a discussion of the impact of the activity cycle and rotation on the observable asteroseismic parameters. We show how our closest star would appear through the eyes of Kepler, CoRoT, and SONG. We discuss the asteroseismic signatures of its 11-year quasi-biennial activity cycles. We then consider the requirements for detection of activity cycles in other solar-type stars (as observed, for example, by Kepler).

A new time-distance measurement of meridional circulation that is not susceptible to center-to-limb effects

Thomas L. Duvall Jr.* and Sudeepto Chakraborty

*NASA Goddard Space Flight Center, Greenbelt, MD, USA
(duvall@sun.stanford.edu)

Meridional circulation (MC) in the solar interior is important to measure for multiple reasons, including its possible connection to the solar dynamo and its importance to the angular momentum balance in the convection zone. At the photospheric level, MC is seen in surface Doppler signals and in correlation tracking of magnetic features. For the surface Doppler measurements, there is a significant center-to-limb signal of the same order as the meridional circulation signal that must be removed. It has not proven possible to use the correlation tracking of granulation to measure MC because of a large center-to-limb signal that mimics a flow. These center-to-limb signals presumably arise from measuring granulation at different heliocentric angles.

Time-distance measurements of MC are also subject to center-to-limb effects, as shown by Zhao et al. And as one increases the separation between points to access deeper layers, the magnitude of the center-to-limb signal increases as the MC signal decreases. To get around this problem, we have developed a new technique that only uses pairs of points at the same heliocentric angle to make travel time difference measurements. As long as the geometry is well-known and the center-to-limb effects are not latitude-dependent, this should obviate the need of center-to-limb corrections. This method has some negative aspects, including being a 1-d measurement subject to significant realization noise and having the large solar rotation signal in the travel times that must be separated. Preliminary measurements from the first year of HMI data and modeling to evaluate the technique will be presented.

Inversion of the two-point velocity correlations on the Sun's surface

Damien Fournier*
*Institute of Applied Mathematics, Göttingen, Germany
(d.fournier@math.uni-goettingen.de)

The two-point velocity correlations are an important quantity to describe turbulence. Theoretically, they could be obtained by inverting for the velocity field then computing the correlations. But in practice the data are too noisy so this naive procedure cannot be used. Here, we will show that the velocity correlations can be obtained directly from the data by using products of travel times. As usual, an inverse problem has to be solved to recover internal properties of the Sun. A good knowledge of the sensitivity kernels and of the noise model is required to perform the inversion reliably. The forward problem can be obtained easily by a convolution between kernels for velocities. Then, a simple formula to compute the noise between products of travel times is derived and validated using SDO/HMI data. Finally, an inversion is performed using SDO/HMI data and compared with synthetic data of velocities in supergranules.

Low-degree and low-order global seismology of the Sun and Stars

Rafael A. Garcia*
*SAp CEA-Saclay, France (rafael.garcia@cea.fr)

Low-degree modes are the only ones that can be accessible from integrated solar and stellar observations. In particular, low-order modes are of particular interest because they have smaller line widths than those at high frequency and they can be determined with higher precision. Moreover, because their external turning points are deeper in the star, they follow smaller perturbations due to the so-called "surface effects" and the changing magnetic activity carrying out most of the weight in the inversions. In this talk we will review the present status of the analysis of the low-frequency modes (below 2 mHz) with 18 years of SoHO observations and how they behaved during the magnetic activity cycles 23 and 24. Finally we will place in a wider context this research on the Sun compared to other solar-like stars observed by Kepler.

Trends in theoretical helioseismology

Laurent Gizon*
*MPI für Sonnensystemforschung, Göttingen, Germany (gizon@mps.mpg.de)

While the forward and inverse problems are relatively well understood in global helioseismology, much work remains to be done in local helioseismology. Methods of computational geo-seismology provide some guidance for future developments in local helioseismology but are not directly applicable (e.g. random wave field, importance of modeling the near field, big observational data sets). I will present an iterative inversion for time-distance helioseismology based on a frequency-domain finite-element forward solver. This approach is promising as it is simple and flexible, it offers the possibility of modeling subtle observational effects, and it can be generalized to any other method of local helioseismology.

Python bindings for NetDRMS

Kolja Glogowski*
*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
(glogowski@kis.uni-freiburg.de)

Abstract missing.

Earth-Affecting Solar Causes Observatory (EASCO): an L5 Mission concept for solar physics and space weather

Nat Gopalswamy, Joseph M. Davila, Frédéric Auchère, Jesper Schou*, Clarence Korendike, Albert Shih, Janet C. Johnston, Robert J. MacDowall, Milan Maksimovic, Edward Sittler, Adam Szabo, Richard Wesenberg, Susanne Vennerstrom, and Bernd Heber

*Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany (schou@mps.mpg.de)

Locating a mission at the Sun-Earth L5 Lagrange point has several key benefits for solar physics and space weather, in particular for studying the origin of solar magnetism and how it relates to the solar sources of coronal mass ejections (CMEs) and corotating interaction regions (CIRs). An L5 vantage point allows making accurate measurements of the magnetic and plasma properties of active regions, filament regions, and coronal holes. Measurements from L5 reduces projection effects as CMEs propagate toward Earth. Helioseismic measurements from L5 when combined with measurements from the Sun-Earth line provide important information on the solar interior where the solar magnetic fields are generated and transported to the atmosphere. Combined measurements of photospheric magnetic fields from L5 and Sun-Earth line provide accurate input to solar wind models. Remote-sensing in EUV and X-rays provide information on magnetic regions before they rotate into Earth view. Combined with the Solar Orbiter mission, an L5 mission would allow us to, at times, view parts of the solar surface from three angles simultaneously and at other times allow us to observe essentially the entire solar surface. In-situ measurements of the solar wind plasma, magnetic field, and solar energetic particles greatly aid the space weather science. This paper provides details on an L5 mission concept known as the Earth-Affecting Solar Causes Observatory (EASCO) recently studied at the Mission Design Laboratory of NASA Goddard Space Flight Center. The mission concept includes seven remote-sensing (photospheric through coronal) and three in-situ instruments to provide a comprehensive set of measurements for solar and space weather studies.

Imaging convection in the solar interior

Shravan M. Hanasoge*

*Tata Institute of Fundamental Research, Mumbai, India
(hanasoge@tifr.res.in)

Seismic analyses of observations taken by the Helioseismic and Magnetic Imager onboard the Solar Dynamics Observatory (satellite) reveal convective velocities that are almost two orders in magnitude smaller than current theoretical and computational predictions. The associated Reynolds' stresses would be too small to explain the observed large-scale flow systems of meridional circulation and differential rotation in the convection envelope of the Sun, throwing into question models of dynamo action. In this talk I will describe the analysis and discuss difficulties associated with rigorously inverting for flows.

Properties of p-mode oscillations observed in strong H-α flares

Frank Hill*, Teresa Monsue, Keivan Stassun

*National Solar Observatory, Tucson, AZ, USA (hill@noao.edu)

We have analyzed H-alpha intensity images obtained at a 60-sec cadence with GONG to investigate the properties of oscillations in the p-mode frequency band at the location and time of strong X-class flares. For each of three flares, we extracted time series in as many as seven sub regions located at physically distinct positions including the flare core and quiet areas outside the flaring region. The time series were analyzed with a wavelet analysis to examine power as a function of frequency and time. We find that, in the heart of all three flares, the low-frequency power ($\sim$1-2 mHz) is substantially enhanced immediately prior to and after the flare, and that power at all frequencies up to 8 mHz is depleted at flare maximum. This depletion is both frequency and time dependent. These variations are not observed outside the flaring region. The depletion may indicate that acoustic energy is being converted into thermal energy at flare maximum, while the low-frequency enhancement may arise from an instability in the chromosphere and provide an early warning of the flare onset.

Farside maps and space weather forecasting

Frank Hill*
*National Solar Observatory, Tucson, AZ, USA (hill@noao.edu)

Observations of p-mode oscillations obtained from Doppler images of the Sun can be analyzed to detect the locations of large active regions on the side of the sun oriented away from the Earth. These farside maps have proven to be very useful in space weather forecasting by providing early warning that a large active region is approaching the east solar limb with a subsequent increase in solar activity. One of Irene's many accomplishments was to develop the farside maps into calibrated estimates of the magnetic field strength, which allowed the use of the maps for more quantitative space weather forecasts. The calibration resulted in:

1. Reduction of discontinuities in coronal magnetic field extrapolations caused by the sudden appearance of an active region on the east limb
2. Improved forecasts of the photospheric magnetic field in data assimilation systems (i.e. ADAPT)
3. Improved forecasts of the 10.7-cm flux
4. Improved forecasts of the background solar wind speed
5. Improved models of solar irradiance variations

Irene also worked on comparing STEREO EUVI and farside signals, and discovered a solar cycle dependence in the average farside signal that probably arises from changes in the solar acoustic radius. Further work is now underway to provide noise estimates in the farside signal, and to develop input for VUV flux forecasts. This talk will review Irene's work in this area and outline future directions.

Persistent near-surface flow structures from ring-diagram analysis of GONG and HMI data

Rachel Howe*
*University of Birmingham, United Kingdom (rhowe@noao.edu)

The inferred near-surface zonal and meridional flow values from ring-diagram analysis of GONG and HMI data show evidence of structures that persist over several rotations; at the higher latitudes seen with HMI these structures are very pronounced. We will present these results and investigate their relationship to the differential rotation and to magnetic and coronal features.

The torsional oscillation and the timing of the solar cycle

Rachel Howe*
*University of Birmingham, United Kingdom (rhowe@noao.edu)

The pattern in global zonal flows known as the torsional oscillation has recently shown some potential to allow us to anticipate the unfolding of the magnetic solar cycle. With Cycle 24 now probably at or past its peak we will discuss the latest results and what inferences we can draw about the declining phase and the next cycle.

Helioseismology at different wavelengths using HMI and AIA

Rachel Howe*
*University of Birmingham, United Kingdom (rhowe@noao.edu)

Although the main focus of helioseismic analysis of the data from HMI has been on the Doppler velocity, the intensity and line-depth observables also show signatures of the five-minute oscillations, as do the 1600 and 1700 Angstrom ultraviolet observations from AIA. This raises the possibility of using the data together for multi-wavelength parameter estimation. We will present some recent results.

Using SDO/HMI observations to detect pre-emergence signatures of large active regions

Stathis Ilonidis*, Junwei Zhao

*W. W. Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA94305-4085 (ilonidis@stanford.edu)

It has been shown that large active regions can be detected by helioseismology before they emerge in the photosphere. The detection method is based on computations of cross-covariances between oscillation signals observed at pairs of locations on the solar surface. In this study, we use SDO/HMI observations to search for pre-emergence signatures of large active regions. For each one of these regions, we monitor the subsurface frequency and phase travel-time perturbations at various depths up to about 75 Mm and for several days before the emergence of magnetic field in the photosphere. The same set of measurements is also applied to quiet regions to obtain estimates of the noise level and evaluate the statistical significance of the perturbations measured in emerging-flux regions. We show examples of detection with the corresponding confidence levels, and discuss the effects of pre-existing surface magnetic fields on our detections.

The MOTH II experiment

S. Jefferies, N. Murphy, B. Fleck*, S. McIntosh, T. Straus, C. Giebink, W. Giebink, L. Heida, W. Rodgers, J. Sasian

*European Space Agency (bfleck@esa.nascom.nasa.gov)

There is a growing need in solar physics to measure the 3-dimensional structure of the Sun's atmosphere, with the primary tools to do this being instruments that can measure velocity and magnetic fields at multiple altitudes. These measurements can provide insight into the transport of energy and magnetic flux in the atmosphere, the emergence of magnetic flux and helicity, the dynamics of transient phenomena such as spicules, and help constrain measurements of the magnetic field emerging into the corona. MOTH II is a ground-based experiment that addresses this need by measuring the line-of-sight velocity and magnetic fields at four heights, from the photosphere to the high chromosphere. The experiment comprises of four individual instruments of identical design. The heart of each instrument is a magneto-optical filter (MOF) that is used to observe the line-of-sight velocity and magnetic field signals over the visible disk of the Sun

with a spatial resolution of 4 arc seconds and temporal resolution of 5 seconds. Each instrument observes a different height in the solar atmosphere. A proof-of-concept run with two of the instruments (equipped with MOFs using the Na 589 nm and K 770 nm solar absorption lines) at Mees Solar Observatory on Maui, showed a velocity and magnetic field sensitivity of ~ 7 m/s and ~ 5 G, respectively, in 5 seconds. We will describe the instruments, discuss their application for helioseismology and other areas of solar research, and present some initial results.

Magnetic field and solar oscillations

René Kiefer*

*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
(kiefer@kis.uni-freiburg.de)

We investigate the effect of the Sun's large-scale magnetic field on the solar eigenfunctions by employing quasi-degenerate perturbation theory. Large-scale flow components are incorporated into the model as well. Observational quantities in form of frequency shifts and perturbations of the eigenfunctions are discussed.

Solar-cycle variation of subsurface flows derived from GONG and SDO/HMI

Rudolf Komm*, Irene González Hernández, Rachel Howe, Frank Hill

*National Solar Observatory, Tucson, AZ, USA (komm@noao.edu)

We study the solar-cycle variation of the zonal and meridional flow in the near-surface layers of the solar convection zone from the surface to a depth of 16 Mm. We have analyzed Global Oscillation Network Group (GONG) and Helioseismic and Magnetic Imager (HMI) Dopplergrams with a ring-diagram analysis covering more than 13 years combined. The zonal and meridional flows vary with the solar cycle. Their amplitude variation tracks the mean latitude of activity and appears more than two years before magnetic activity is visible at the solar surface during the beginning of cycle 24. We focus on the variation of the zonal and meridional flows and their long-term variation at mid- and low-latitudes using GONG and HMI data and on their variation at high latitudes that are now accessible using HMI data.

Current and kinetic helicity of long-lived activity complexes

Rudolf Komm*, Sanjay Gosain

*National Solar Observatory, Tucson, AZ, USA (komm@noao.edu)

We focus on long-lived activity complexes and their helicity below and above the solar surface. Long-lived activity complexes are locations of recurrent flux emergence in or close to a pre-existing active region and typically last for five to seven solar rotations. The newly emerging magnetic flux in pre-existing magnetic regions causes an increase in topological complexity of the magnetic field, which leads to flares and CMEs. Quantitative measures of topological complexity are the magnetic helicity measuring twisting and linking of the magnetic field in the solar atmosphere and the kinetic helicity measuring twisting of associated flows below the solar surface. Here, we focus on the sign of the current and kinetic helicity of long-lived activity complexes observed with GONG, SDO/HMI, and SOLIS/VSM during April 2011 to January 2013.

What can we learn about the solar subsurface large scale flows from accurate high-degree modes frequencies?

S.G. Korzennik*
*Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA
(skorzennik@cfa.harvard.edu)

I present results from the characterization of high-degree modes based on three instruments (MDI, HMI and GONG) and carried out for three epochs. The data sets analyzed all correspond to MDI Dynamics runs epochs, and are 90 days of MDI observations in 2001, 98 days of MDI and GONG in 2002 and 67 days of MDI, GONG and HMI in 2010. The full disk dopplergrams were spatially decomposed up to $\ell = 900$ (GONG) and up to 1000 (MDI and HMI). Power spectra for all degrees and all azimuthal orders were computed using a multitaper power spectrum estimator and these spectra were then fitted for all degrees and all azimuthal orders, between $\ell = 100$ and $\ell = 900$ or 1000, and for all orders with substantial amplitude. This fitting generated some $5 \cdot 10^6$ individual estimates of ridge frequencies, line-widths, amplitudes and asymmetries (singlets), corresponding to some 6,000 multiplets (ℓ, n).

Since individual modes blend into ridges at high degrees, this fitting generates ridge characteristics, characteristics that do not correspond to the underlying mode characteristics. I used a sophisticated forward modeling to recover the best possible estimate of the underlying mode characteristics (mode frequencies, as well as line-widths, amplitudes and asymmetries).

I present results from this first attempt to apply this methodology to three instruments and three epochs. The derived sets of corrected mode characteristics are presented and compared, and the resulting rotation inversions, using intermediate degree only and intermediate and high degree splittings, are presented and discussed.

Fitting resolved modes using GONG, MDI and HMI observations

S. G. Korzennik*
*Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA (skorzennik@cfa.harvard.edu)

I present results from fitting all the available observations from the three major helioseismic instruments: GONG, MDI, and HMI, at medium degrees, i.e., for resolved modes. The observations were fitted by the respective projects' pipelines and by my state of the art fitting methodology. I compare and contrast the changes in the resulting mode characteristics, not only in terms of frequency variation with epochs (hence solar activity), but also in terms of changes in mode lifetimes (FWHM) and their asymmetries. The clear variations with activity seen in my estimates of the FWHM and asymmetry parameters are only hinted in the projects' estimates.

I also present changes in the solar rotation rate inferred form inverting over 15 years of observations. These changes, namely the departure of the rotation from a mean rotation, are shown as a function of time, depth and latitude, throughout the convection zone. This residual rotation, also known as the torsional oscillations, is illustrated in terms of propagation diagrams to better show how Cycle 24 differs from Cycle 23.

Modeling solar dynamics

Manfred Küker*
*Leibniz-Institut für Astrophysik Potsdam, Germany (mkueker@aip.de)

Mean field theory allows us to model solar and stellar dynamos with very modest use of computing power. The same theoretical framework that explains the solar activity cycle with the flux transport dynamo can be used to model the differential rotation and the large-scale meridional flow that are vital ingredients of the dynamo. We discuss the current model of the solar differential rotation, the flow pattern it produces, and the importance of the Reynolds stress versus baroclinity. We then apply it to other stars on the lower main sequence, pre-main sequence stars, and subgiants, and compare its predictions with current observations. We also address current and upcoming challenges in modelling the internal dynamics of the Sun.

Spatially resolved vorticity in supergranulation with helioseismology

J. Langfellner*, L. Gizon, A.C. Birch

*Universität Göttingen / Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany (jlangfe@astro.physik.uni-goettingen.de)

We present a time-distance helioseismology method that measures the vertical component of flow vorticity in solar supergranulation. Using SDO/HMI Dopplergrams, the method reproduces the findings by Gizon & Duvall (2003) that supergranular outflows are on average associated with clockwise flows in the northern hemisphere and counter-clockwise flows in the southern hemisphere. This is consistent with the expected effect of the Coriolis force. For the first time, we spatially resolve the vertical vorticity of an average supergranule and supergranular junction at various solar latitudes. Away from the equator, the spatial structure of the vertical vorticity resembles the structure of the flow divergence. At the equator, there is no visible vorticity structure. We find matching structures for the vorticity measured from local correlation tracking (LCT) of granules seen in HMI intensity images. Using LCT, we also characterize the flow circulation as a function of distance to the supergranule center/junction and compare it to the horizontal outflow component. The peak circulation velocity is roughly 10 m/s around both supergranule centers and junctions, which is a factor of about 30 and 20 weaker than the outflow/inflow velocities.

Medium-degree analysis of Mount Wilson data

T. Larson*, S. Pinkerton, E.J. Rhodes, Jr, J. Schou

*Stanford University, Stanford, CA, USA (tplarson@sun.Stanford.EDU)

Between 1988 and 2006, the 60-foot solar tower at Mount Wilson Observatory took Doppler measurements every summer. Our previous work examined the summer of 1996 and compared the results with contemporaneous data from MDI. Although we observed significant differences for the f-mode, the overall comparison was highly encouraging. In the current work we correct for the daily variation of the MWO P-angle in order to get even better agreement. We also analyze MDI data using the same window function to determine the extent to which this factor contributes to the difference between the two instruments. After making more comparisons during solar cycle 23, we use the MWO data to draw inferences

about solar cycle 22, during which MWO provided the only long helioseismic dataset available.

Helioseismic diagnostics of solar flares

John Leibacher*, Frédéric Baudin, Maria Cristina Rabello Soares

*National Solar Observatory (NSO), Tucson, Arizona, USA
(`jleibacher@nso.edu`)

Flares are known to excite waves in the solar atmosphere. Maurya et al. (2009), using a local analysis (ring diagrams) of the 2003 Halloween flare, also showed they excite p-modes. We confirm and extend here these results by:

- applying the same analysis to other locations on the Sun at the time of the Halloween flare
- analyzing another event also showing a signature of p-mode excitation
- looking in details at the results of the ring diagrams analysis in terms of noise fitting.

The Halloween flare present an apparent localized excitation of p-modes, similar to what is observed for the other event analyzed.

Flares have been thought to excite acoustic oscillations of the Sun since the 1970's (Wolf). Later, signature of flares were observed in Doppler photospheric velocities (Kosovichev & Zharkova). Then, several cases of excitation of photospheric waves and of p-modes were reported (Donea, Ionescu, ...). We investigate here the case of low degree p-modes, observed to be excited by flares by Karoff & Kjeldsen, and the case of higher degree modes, observed to be excited by, for example, Maurya et al. If low degree modes seem not to be excited by flares, we characterize which higher degree modes are sensitive to flares.

Seismic mapping of the Sun's far hemisphere

Charles Lindsey*

*NorthWest Research Associates, Boulder, CO, USA
(clindsey@cora.nwra.com)

I will summarize the development of helioseismic mapping of the Sun's far hemisphere over the last decade and a half and its role in the recognition and development of local helioseismology since the late 1980s. Included will be a brief summary of the principles of computational seismic holography and the role of far-side solar mapping in its development. I will emphasize the crucial role of Irene Gonzalez Hernandez in the development of far-side seismic holography as a practical synoptic tool and its introduction to a growing school of practical applications in solar synoptics and space-weather forecasting.

I will finally review recent improvements in the technique of far-side helioseismology and outline further improvements under development.

Image compression in local helioseismology

Björn Löptien*

*Universität Göttingen / Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany (loeptien@astro.physik.uni-goettingen.de)

Several upcoming helioseismology space missions, such as e.g., Solar Orbiter, are going to be very limited in telemetry and will have to perform extensive data compression. In particular, it will probably be necessary to implement lossy methods, which involve a trade-off between the compression efficiency and artifacts caused by the compression. Here we focus on one of the most basic measurements: time-distance helioseismology of supergranulation flows at disk center. All of the compression methods that we tested (quantization, JPEG compression, and smoothing and subsampling) allow us to probe these flows using Dopplergrams with a file size of less than a bit per pixel. We achieve the best results by applying JPEG compression on spatially subsampled data. We also present first results showing differential rotation determined from compressed data using time-distance helioseismology and granulation tracking.

Helioseismology with Solar Orbiter

Björn Löptien*

*Universität Göttingen / Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany (loeptien@astro.physik.uni-goettingen.de)

The *Solar Orbiter* mission, to be launched in July 2017, will carry a suite of remote sensing and in-situ instruments, including the *Polarimetric and Helioseismic Imager* (PHI). PHI will deliver high-cadence images of the Sun in intensity and Doppler velocity suitable for carrying out novel helioseismic studies. The orbit of the *Solar Orbiter* spacecraft will reach a solar latitude of up to 21° (up to 34° by the end of the extended mission) and thus will enable the first local helioseismology studies of the polar regions. Here we consider an array of science objectives to be addressed by helioseismology within the baseline telemetry allocation (51 Gbit per orbit, current baseline) and within the science observing windows (baseline 3×10 days per orbit). A particularly important objective is the measurement of large-scale flows at high latitudes (rotation and meridional flow), which are largely unknown but play an important role in flux transport dynamos. Repeated observations over the course of the mission are also needed to study temporal variations with the solar cycle. The full range of Earth-Sun-spacecraft angles provided by the orbit will enable helioseismology from two vantage points by combining PHI with another instrument: stereoscopic helioseismology will allow the study of the deep solar interior and a better understanding of the physics of solar oscillations in both quiet Sun and sunspots. The low telemetry rate of *Solar Orbiter* requires to perform extensive data compression. In particular, it will probably be necessary to implement lossy methods, which involve a trade-off between the compression efficiency and artifacts caused by the compression. Here we present results for one of the most basic measurements: time-distance helioseismology of supergranulation flows at disk center. All of the compression methods that we tested (quantization, JPEG compression, and smoothing and subsampling) allow us to probe these flows using Dopplergrams with a file size of less than a bit per pixel. We achieve the best results by applying JPEG compression on spatially subsampled data. We also present first results showing differential rotation determined from compressed data using time-distance helioseismology and granulation tracking.

Formation of magnetic flux concentrations and observational implications

Illa R. Losada*
*Nordita and Astronomy Department Stockholm, Sweden
(illa.rivero.losada@gmail.com)

The formation of sunspots is still an unsolved problem in solar physics. Different kinds of observations constrain the problem and the theories that might explain them. Furthermore, any suitable theory must involve the solar dynamo, another problem still under debate. The most popular sunspot theory links both phenomena through flux tubes of magnetic fields that rise throughout the convection zone and emerge at the surface. In spite of successes in explaining several observational constraints, some questions lack a satisfactory explanation, e.g., the magnetic field storage mechanism and the survival of a tube rising in a turbulent medium. Simulation-wise, the formation of a sunspot using the flux tube approach has always required a pre-injected flux tube at the bottom of the computational domain, which is normally just a small fraction of the convection zone. These problems have motivated us to try another theoretical approach to the problem, using the Negative Effective Magnetic Pressure Instability (NEMPI). The basic mechanism that operates in this instability is the fact that the effective magnetic pressure, a combination of the mean magnetic pressure and the turbulent pressure, can have a negative contribution to the total pressure. This negative contribution is compensated for by an increase of the gas pressure in the location of the instability, resulting therefore in a local concentration of magnetic field. The growth of the magnetic field concentration becomes, then, a shallow phenomenon, instead of a deeply rooted one. In this talk I will describe briefly the mathematical concepts and present my contributions to and various other aspects of this research. In particular I will discuss how rotation influences the instability, focussing on the effects of a corona layer on top of the turbulent stratified medium.

Selected references:

Losada, I. R., Brandenburg, A., Kleeorin, N., Mitra, D., & Rogachevskii, I.: 2012, "Rotational effects on the negative magnetic pressure instability," Astron. Astrophys. 548, A49

Losada, I. R., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2013, "Competition of rotation and stratification in flux concentrations," Astron. Astrophys. 556, A83

Warnecke, J., Losada, I. R., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2013, "Bipolar magnetic structures driven by stratified turbulence with a coronal envelope," Astrophys. J. Lett. 777, L37

What can we learn from directional time-distance probing of solar magnetic regions?

Hamed Moradi* and Paul S. Cally

*Monash University, Clayton, Victoria, Australia (hamed.moradi@monash.edu)

In a series of theoretical studies, Cally & Moradi (2013) and Moradi & Cally (2014, 13) quantified the implications of MHD mode conversion for the seismology of the photosphere, by using 3D MHD simulations of helioseismic wave propagation in simple translationally invariant atmospheres to compare Alfvénic losses higher up in the solar atmosphere with helioseismic travel-time shifts at the surface. These results demonstrated that the seismic waves' journey through the solar atmosphere can indeed affect the wave travel times that are the basis of our inferences about the subsurface, and in particular these effects are directional, depending on the orientation of the magnetic field. We will present results from recent work which has aimed to extend this innovative 'directional helioseismology' method to study the more complex sunspot problem.

SDO/HMI multi-height velocity measurements

Kaori Nagashima*

*MPI für Sonnensystemforschung, Göttingen, Germany (nagashima@mps.mpg.de)

To extract multi-height velocity information using a set of SDO/HMI filtergrams, we generate synthetic filtergrams and explore a wide range of methods for estimating Dopplergrams using the convection simulation datasets provided by STAGGER and MURaM codes. On the basis of the investigation, we conclude that we can obtain velocity information from layers separated by about a half of a scale height around the photosphere using HMI filtergrams.

Simulating acoustic waves in spotted stars

Emanuele Papini*

*MPI für Sonnensystemforschung, Göttingen, Germany (papini@mps.mpg.de)

Asteroseismology is a primary tool to provide information and new insights on the relationship between the internal structure of stars and their surface magnetic activity. Numerical simulations are the key to interpret these observations, through the study of the interaction of the acoustic-wave field with 3D perturbations (e.g spots and active regions) to a background model. In this contest we present preliminary results of a parametric study of the effect on selected modes for l=0,1,2 induced by a spot-like perturbation in the sound speed with respect to a convectively stabilised solar Model S. This perturbation is located at the surface and at depths of 0.01 up to 0.03 solar radii, with amplitude changes in the squared sound speed that range from 10% to 100%. For the simulations we used the GLASS code, currently in development, which allows simulation of propagating acoustic waves through a generic full 3D rotating stellar interior, including the centre.

Pioneering works on ring diagram analysis with Irene González Hernández

Jesús Patrón*

*Instituto de Astrofisica de Canarias, Canary Islands, Spain (jpr@iac.es)

Irene González Hernández started her graduate studies at the University of La Laguna (Canary Islands, Spain) on 1993. From 1994 to 1998, she developed the necessary research works related to her PhD Thesis "Sinoptic map of transversal flows at the higher layers of the solar convection zone". During that period of time I had the opportunity, the pleasure and the privilege of sharing my own post-doctoral research work on ring diagram analysis developments, obtaining important improvements to the current methodology and finalizing with the largest mapping of the horizontal velocity flows under the solar surface at the moment. In this presentation I will just summarize the most important works performed.

Oscillatory and radiative properties of a sunspot model

Damien Przybylski*

*Monash University, Clayton, Victoria, Australia (damien.przybylski@monash.edu)

A Sunspot Model has been produced that is convectively stable under linear perturbations, yet has a realistic thermodynamic parameters in the photosphere and absorption line formation region. The numerical code SPARC can then be used to introduce perturbations into the sunspot and model the magneto-acoustic waves. The spectral line profiles can then be synthesised and their response to these waves investigated. Finally we can compare the effect of instrumental degradation, and position on the solar surface on the observed physical behaviour.

Solar structure as seen by high-degree modes

M. Cristina Rabello Soares*

*Departamento de Fisica - ICEx - UFMG, Belo Horizonte, MG, Brasil
(cristina@fisica.ufmg.br)

The near-surface layers of the Sun using inversions of acoustic mode frequencies including high-degree modes are analyzed. We use the new precise frequencies obtained by Korzennik et al (2013) applying spherical harmonic decomposition to MDI dopplergrams. We also use frequencies observed at magnetically quiet regions obtained by Rabello-Soares et al. (2013) applying ring diagram analysis to HMI dopplergrams to investigate the perturbation in the solar structure due to a nearby active region. To suppress the uncertainties in the surface layers in helioseismic models, a "surface term" developed using a higher-order asymptotic theory suitable for high-degree mode frequencies (see Di Mauro et al. 2002) is used.

Activity, rotation and stellar ages using *Kepler*

Timo Reinhold*

*Institut für Astrophysik, Georg-August-Universität Göttingen, Germany
(reinhold@astro.physik.uni-goettingen.de)

With CoRoT and Kepler a new era of high-precision photometry has begun. Measurements of surface rotation periods have been achieved for tens of thousands of stars,

unprecedented in their number and accuracy (McQuillan et al. 2014; Reinhold et al. 2013; Nielsen et al. 2013). Surface differential rotation and spot evolution manifest through multiple rotation periods in the lightcurve making it obsolete to speak of "the" stellar rotation period. Analyzing Kepler Q1-Q16 data using the Lomb-Scargle periodogram we present rotation periods, differential rotation measurements, and age estimates using gyrochronology relations for thousands of active Kepler stars. In this context we also discuss current activity-rotation-age relations.

Probing the solar interior on multiple timescales using global helioseismology

E.J. Rhodes, Jr*, A.G. Kosovichev, T.P. Larson, J. Reiter, P. Scherrer, J. Schou, and S. Pinkerton

*USC, Physics-Astronomy Dept, Los Angeles, CA, USA (erhodes@usc.edu)

In this talk we will present several new results that we have obtained recently concerning temporal changes in the seismic properties of the outer portion of the solar convection zone and in the solar Subsurface Shear Layer (SSL) on timescales that vary from only a few days to 26 years. We will describe how we were able to carry out these studies by employing improved global helioseismic methods on an extensive combination of ground- and space-based solar observations that began in mid-1988 and which covered portions of Solar Cycles 22, 23, and 24. First, we will summarize briefly the improvements that we have made in the generation and fitting of global helioseismic power spectra. We will point out that these improvements have included the use of refined information on the distortion of the solar images in the space-based instruments, the use of improved estimates of the position angle and inclination angle of the solar spin axis in the generation of the oscillation power spectra, and the implementation of refinements to the methods that we have employed in the fitting of the peaks in these power spectra. Second, we will demonstrate that, by dividing the multi-year time series of global observations into time series that were each only three days in duration, we have discovered that the solar oscillation frequencies and their widths exhibit similar, but distinctly different, patterns of temporal changes in response to changing levels of solar activity. Third, by repeating these comparisons of the short-term changes in the oscillation frequencies and widths over widely-separated portions of the past three solar cycles, we have been able to study long-term changes in the acoustic cutoff frequency of the solar atmosphere, and we have also been able to discover an extreme excursion in the sun's seismic properties during the 2008-2009 extended solar minimum. Fourth, we will demonstrate that, by employing longer time series of up to four months in duration, by systematically cleaning the resulting frequency tables of outliers, and by performing structural inversions of the cleaned tables, we have been able to show that the internal sound speed in the outer half of the convection zone and in the SSL is

systematically lower than is the sound seed in the standard solar model. Lastly, we will point out that, by carrying out these structural inversions during both the 2001 solar maximum and during the rising phase of Cycle 24, we have been able to demonstrate the existence of corresponding temporal changes in the internal sound speed in the outer convection zone and in the SSL.

Photospheric fast wave refraction as a mechanism for the acoustic halo

Carlos Rijs*

*Monash University, Clayton, Victoria, Australia (carlos.rijs@monash.edu)

We attempt to explain the local acoustic halo phenomenon using mode conversion of fast Magneto-hydrodynamic waves which refract and then reflect downwards, depositing excess energy into regions of moderate field strength and horizontal inclination. These halos are manifested as an excess of time averaged acoustic power (relative to the quiet sun) in the high frequency range (> 5.5 mHz). The mechanism seems to be supported quite well by recent observations and simulations and we have carried on the recent work of Khomenko & Collados (2009) and others by modelling the halo region in 3D with a variety of magnetic field configurations - including MHS sunspots - and wave pulses. Early results seem to indicate that halo formation spreads out horizontally with height, following the a=c line, which is promising for the validity of the mechanism.

Exploitation of space data for innovative helio- and asteroseismology (SPACEINN)

Markus Roth*

*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany (mroth@kis.uni-freiburg.de)

The European Helio- and Asteroseismology Network (HELAS) has initiated the follow-up project "SpaceInn - Exploitation of Space Data for Innovative Helio- and Asteroseismolgoy" with the mission to build on the existing European strength in the field of time-domain stellar physics. SpaceInn activities, which are organized around the themes of data access, scientific expertise and existing coordination, aim to secure optimal use of the existing and planned data, from space and from the ground, in helio-

and asteroseismology. Starting on January 1, 2013, the SpaceInn project is funded for four years by the European Union. In this presentation we will give an overview on the upcoming activities of SpaceInn.

SPRING: A new ground-based network for synoptic solar observations

M. Roth*, S. Gosain, F. Hill, M. J. Thompson

*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
(mroth@kis.uni-freiburg.de)

SPRING is a project to develop a network of instrumentation to obtain synoptic solar observations. Building on the demonstrated success of networks to provide near-continuous long-term data for helioseismology, SPRING will provide data for a wide range of solar research areas. Scientific objectives include internal solar dynamics and structure; wave transport in the solar atmosphere; the evolution of the magnetic field over the activity cycle; irradiance fluctuations; and space weather origins. Anticipated data products include simultaneous full-disk multi-wavelength Doppler and vector magnetic field images; filtergrams in H-Alpha, CaK, and white light; and PSPT-type irradiance support. Data will be obtained with a duty cycle of around 90% and at a cadence no slower than one minute. SPRING will also provide context information for large-aperture solar telescopes such as EST and the DKIST. The current concept is a multi-instrument platform installed in at least six locations.

The existence of the Λ effect in the solar convection zone as indicated by SDO observations

Günther Rüdiger*, Manfred Küker

*Astrophysical Institute Potsdam, Germany (gruediger@aip.de)

The finding of Hathaway et al. (2013) of positive (negative) horizontal Reynolds stress at the northern (southern) hemisphere for solar giant cells is discussed after its consequences for the theory of the solar differential rotation. Solving the nonlinear Reynolds equation for the angular velocity (under neglect of the meridional circulation) leads to horizontal Reynolds stress in the northern hemisphere which is positive in the bulk of the solar convection zone by the action of the Lambda effect. The Lambda effect, which

describes the angular momentum transport of rigidly rotating anisotropic turbulence, in horizontal direction is of cubic order in the rotation rate and it is always directed towards the equator. Theories without Lambda effect which may correctly provide the observed solar rotation law by the action of a meridional circulation lead to the horizontal Reynolds stress with the opposite sign as observed.

Distortion of global mode eigenfunctions

Ariane Schad*
*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
(ariane.schad@kis.uni-freiburg.de)

Recently, we investigated the meridional flow in the solar interior by analysis of the distortion of p-mode eigenfunctions. The eigenfunction distortions are measured from amplitude ratios between global oscillations decomposed in spherical harmonics. Here, we consider the extension of this mode eigenfunction distortion analysis to measure also solar rotation in the convection zone from MDI data. The results are compared to rotation profiles from frequency splittings. This analysis will help to further investigate the reliability of flow measurements in the solar interior.

Interaction of waves with solar convection

Jesper Schou*, Björn Löptien, Charles Baldner
*MPI für Sonnensystemforschung (schou@mps.mpg.de)

As discussed in Baldner & Schou (2012), the strong asymmetry between the upflows and downflows in the near surface convection leads to significant observable effects for the Sun. Here we attempt a more detailed analysis of the effect using simulations, improved analytical treatment of the wave/convection interactions and more detailed radiative transfer. We also compare the simulation results with solar observations.

Sunspot seismology

Hannah Schunker*
*MPI für Sonnensystemforschung, Göttingen, Germany (schunker@mps.mpg.de)

Traditionally, the subsurface structure of sunspots has been inferred using local helioseismic techniques treating the sunspot as a weak perturbation to the waves, however the surface of the sunspot has a strong effect on the waves. Using 3D MHD simulations of the response of seismic waves to sunspot models with various perturbations, we find that subsurface sound-speed perturbations to a sunspot model introduce smaller travel-time-shifts than perturbations to the quiet-Sun. Changes in the wave amplitude also provides information about the perturbations to the sunspot. Helioseismic analysis of the observations suggests that the scattering of waves due to the sunspot contributes to the wave amplitude reduction, in addition to the mode-conversion. In addition, the scattered waves constructively interfere with the unperturbed rays enhancing the amplitude of the waves away from the central ray path. Wave amplitude measurements are an untapped source of independent information that may be used in addition to travel-time calculations.

Catalogue of emerging active regions observed by HMI (May 2010-Dec 2012)

Hannah Schunker*
*MPI für Sonnensystemforschung, Göttingen, Germany (schunker@mps.mpg.de)

In an effort to helioseismically detect and study active regions before, during and after emergence, we have identified 105 emerging active regions observed by SDO/HMI between May 2010 to December 2012. For each emerging active region we have tracked close to 40 datacubes each covering about 7 hours, up to 6 days before and after emergence, of both line-of-sight magnetic field and Doppler velocity observations. In addition, for each emerging active region we identified and identically processed a corresponding quiet-Sun region. The Doppler velocities were then analysed using helioseismic holography to obtain travel-time maps using both surface-focusing and deep-focusing geometries. This is the largest catalogue of emerging active regions observed by SDO/HMI to-date, containing over 8TB of data, processed by and stored in the German Data Centre for SDO that is housed at the MPS.

Rotation of KIC 11145123

Sekii, T.*, Kurtz, D.W., Saio, H., Takata, M., Shibahashi, H., Murphy, S.

*National Astronomical Observatory of Japan (NAOJ), Mitaka, Tokyo, Japan (sekii@solar.mtk.nao.ac.jp)

Investigating solar and stellar rotations is of paramount importance for our continued effort to understand solar and stellar dynamo. Rotationally split modes have been discovered for a terminal-age main-sequence A star, KIC 11145123, which oscillates both in p modes and g modes, thus permitting us to estimate robustly the rotation of the deep core and surface. The star is found to be rotating almost uniformly but with compelling evidence that the surface layer rotates slightly faster than the deep core.

Spectropolarimetric signatures of mode conversion in simulated sunspots

Sergiy Shelyag*

*Monash University, Clayton, Victoria, Australia (sergiy.shelyag@monash.edu.au)

We present the results of numerical simulations of wave propagation through a large-scale magnetic field concentration mimicking a sunspot, embedded in a convectively stable solar-like sub-photosphere and the realistic solar photosphere. The sunspot model we created allows us to study the response of photospheric radiation to a sub-photospheric plasma perturbation and, therefore, to directly link the simulations with observational data. Using the model, we show the presence of signatures of fast-to-slow magneto-acoustic mode conversion in the simulated observations of the sunspot umbra at different positions at the solar disk. Despite similar signatures in sunspot umbrae are observed, possible presence of stray light in the observations prevents us to draw ultimate conclusions.

Properties of p and f modes in hydromagnetic turbulence

Nishant Kumar Singh*

*Nordita, Stockholm, Sweden (nksi@kth.se)

With the ultimate aim of using the fundamental or f-mode to study helioseismic aspects of turbulence-generated magnetic flux concentrations, we use randomly forced hydromagnetic simulations of a piecewise isothermal layer in two dimensions with reflecting boundaries at top and bottom. We compute numerically diagnostic wavenumber-frequency diagrams of the vertical velocity at the interface between the denser gas below and the less dense gas above. We study the effects of uniform (both horizontal and vertical) as well as nonuniform magnetic field on especially the f mode and discuss some novel features that we find. Based on our new findings, we argue that the f-mode could be used as a sensitive tool to determining subsurface magnetic fields.

Recent results on surface flow fields from timeâdistance helioseismology

Michal Švanda*

*Astronomical Institute, Academy of Sciences, Ondřejov observatory, Ondřejov, Czech Republic (michal@astronomie.cz)

Solar photosphere and the shallow layers below are a very dynamical system. Plasma motions occur on scales from moving features smaller than granules, i.e. $\sim$100 km, to structures having a size comparable to the solar radius, i.e. $\sim$100 Mm. Local helioseismology is a useful tool to address plasma motions. Recent results obtained by means of local helioseismology will be shortly discussed.

Cross-spectral fitting of GONG and HMI oscillation data

S. C. Tripathy*, C. Barban, K. Jain, S. Kholikov and F. Hill

*National Solar Observatory, Tucson, AZ, USA (stripathy@nso.edu)

Simultaneous measurements of various observables at different heights in solar atmosphere offer the prospect of studying the sensitivity of helioseismic inferences to the

choice of observed height. These measurements can also be used to provide better estimates of oscillation mode parameters that can be obtained by fitting four spectra simultaneously viz. velocity, intensity, the phase difference and the coherence between the intensity and velocity spectra. Using GONG and HMI data, we will compare the mode parameters obtained from a single-observable and those from cross-spectral fitting method.

Horizontal flows in active regions from multi-spectral observations of SDO

S.C. Tripathy*, K. Jain, B. Ravindra and F. Hill

*National Solar Observatory, Tucson, AZ, USA (stripathy@nso.edu)

Helioseismic Magnetic Imager (HMI) and Atmospheric Imaging Assembly (AIA) on board Solar Dynamics Observatory (SDO) are providing high-resolution and high-cadence full-disk images in various wavelength bands that can also be used in helioseismic studies. Here we present results on the horizontal flow measurements in a few active regions. The flows are calculated using the local helioseismic technique of ring-diagrams. We also present a detailed comparison between horizontal flows in the shear layer below the surface from ring-diagram analysis and the photospheric layer from the local correlation method.

The OPAC International Consortium

S. Turck-Chièze* and the OPAC international consortium

*Laboratory Simulation of Astrophysical Plasmas, SAp/IRFU/CEA, CE Saclay, France (Sylvaine.Turck-Chieze@cea.fr)

Helioseismic measurements and solar neutrinos have put in evidence some misunderstanding problem in radiative zones of solar-like stars which may impact on the determination of age and mass of solar-like stars. These measurements can also reveal some underestimation of the dynamics of the deep radiative zone that is difficult to put in evidence. It is why different activities have been taking placed since 5 years to establish the reliability of the opacity calculations used in stellar physics, the way one uses them and to realize or prepare experiments. All these activities have the objective to check used calculations and to prepare new ones. So this talk is a summary of what we have already realized, what we believe and what we prepare near the high energetic lasers

like LMJ that enters in activity at the end of this year or like NIF at Livermore. These activities will contribute to better interpret the helio and asteroseismic results. Most of these activities are funded by the ANR Opacity and our GOLF CNES contract.

A Fourier-Legendre analysis module for the SDO Data Analysis Pipeline

G. Vigeesh*, K. Glogowski, H.-P. Doerr, and M. Roth

*Kiepenheuer-Institut für Sonnenphysik, Schöneckstrasse 6, 79104 Freiburg, Germany (vigeesh@kis.uni-freiburg.de)

Fourier-Legendre analysis is one of the helioseismic techniques employed to infer the internal properties of the Sun. It has been successfully applied to study p-mode absorption by sunspots and to measure sub-surface meridional flow. In this work, we implemented a Fourier-Legendre analysis module on the SDO/HMI JSOC data-analysis pipeline. We present here the details of the pipeline module and some preliminary results.

Seismic diagnostics of the equation of state and element abundances in the solar envelope

S.V.Vorontsov*, V.A.Baturin, S.V.Ayukov, V.K.Gryaznov

*Astronomy Unit, Queen Mary University of London, United Kingdom (S.V.Vorontsov@qmul.ac.uk)

We discuss the results of our current efforts in using p-mode frequency measurements obtained from SOHO MDI "medium-l" data for addressing the accuracy of recent versions of the equation of state and the chemical composition of the solar convective envelope. We implement two diagnostic techniques, which supplement each other: (a) direct calibration of the parameters of the adiabatically-stratified part of the solar convective envelope, with using the p-mode frequencies directly and with using group velocities of surface waves inferred from the p-mode data, and (b) a constrained iterative structural inversion. All our results support the downward revision of heavy-element abundances in the solar envelope.

Simulations modeling global turbulent convective dynamos of the Sun with and without coronal envelope

Jörn Warnecke*
*MPI für Sonnensystemforschung, Göttingen, Germany (warnecke@mps.mpg.de)

Global simulations of turbulent convective dynamos are now able to reproduce many features observed on the Sun. The mean magnetic field shows a clear equatorward migration and the differential rotation has a conical spoke-like structure. At the moment not all these features and their origin are well understood in the simulations and we do not know, if the driving mechanisms are the same as in the Sun. In this work we report on results obtained by spherical wedge simulations of turbulent convective dynamo action with and without a coronal envelope. This coronal envelope resambles a "free" boundary for the magnetic field and the temperature fluctuations. We find that the turbulent velocity in the near-surface layers play an important role to generate the equatorward migration of the mean magnetic field. Runs with coronal envelope show different magnetic field pattern but prefere a spoke-like differential rotation with multi-cellular meridional circulation. This non-cylindrical rotation profile is caused by a non-zero latitudinal entropy gradient that offsets the Taylor-Proudman balance through the baroclinic term. With the addition of a coronal envelope, the differential rotation also seems to overcome the anti-solar rotation regime for low rotation rate. As the matter of fact, simplified spherical forced turbulent simulations indicate that the dynamo action benefits substantially from the presence of a corona becoming stronger and more realistic.

Investigation of solar oscillations with the HELLRIDE instrument

Aneta Wisniewska*
*Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
(aneta.wisniewska@kis.uni-freiburg.de)

We investigate the propagation of high frequency waves in the solar atmosphere under magnetic and non-magnetic environmental conditions. Based on propagating acoustic waves we want to better understand the structure of the magnetised atmosphere, the energy transport through the solar atmospheric layers, and the chromospheric temperature jump. We carry out the observations with the newly developed instrument HELLRIDE at the Vacuum Tower Telescope on Tenerife.

Time-distance farside imaging using SDO/HMI data

Junwei Zhao*
*W. W. Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA94305-4085 (junwei@sun.stanford.edu)

Encouraged by Irene Gonzalez-Hernandez eight years ago to provide an independent far-side imaging technique in addition to the already well-developed helioseismic holography far-side imaging method, we started to work on developing a time-distance far-side imaging method. We not just successfully imaged the far-side active-region images using 4-skip acoustic signals, but also demonstrated that the 5-skip acoustic signals could also be used to implement the 4-skip method. A combination of both measurement schemes was able to enhance the signal-to-noise ratio, and provided more reliable images of the far-side active regions. Now, we apply the same measurement techniques on HMI data. The availability of far-side images using both helioseismic holography and time-distance techniques allows the data users to cross-check these results so as to use the data with a higher confidence.

Fast-moving waves propagating from penumbra to outside of sunspots in the photosphere

Junwei Zhao*, Ruizhu Chen, and Thomas Hartle
*W. W. Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA94305-4085 (junwei@sun.stanford.edu)

It is well known that different types of magnetohydrodynamic waves and oscillations exist in and above sunspots from the photospheric level through the chromosphere to the corona. The SDO/HMI provides continuous observation of the Sun with a high spatial resolution and temporal cadence, and this allows us to monitor the wave activities around sunspot areas in the photospheric level with an unprecedented quality. Using time-distance helioseismic analysis technique, we identify fast-moving waves traveling along the sunspot's radial direction from the sunspot penumbra to approximately 30 megameters outside of the sunspot. The apparent speed of the wave is about 45 km/s, far exceeding the typical acoustic wave speed in the photospheric level, and also faster than the penumbral waves observed in the chromosphere. The dominant frequency of this newly detected wave is about 3 mHz, falling into the category of 5-minute oscillation. The observation is compatible with a wave source at a depth of about 8 megameters beneath the sunspot's surface, and the above-described waves are expanding wavefronts sweeping across the photosphere.