MHD waves and seismology of the solar atmosphere

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About the Phaistos Disk, used in our cover logo…

The Phaistos Disk is a disk of fired clay from the Minoan palace of Phaistos on the Greek island of Crete, possibly dating to the middle or late Minoan Bronze Age (2nd millennium BC). It is about 15 cm in diameter and covered on both sides with a spiral of stamped symbols. Its purpose and meaning, and even its original geographical place of manufacture, remain disputed, making it one of the most famous mysteries of archaeology. This unique object is now on display at the archaeological museum of Heraklion.

The disc was discovered in 1908 by the Italian archaeologist Luigi Pernier in the Minoan palace-site of Phaistos, and features 241 tokens, comprising 45 unique signs, which were apparently made by pressing pre-formed hieroglyphic ‘seals’ into a disc of soft clay, in a clockwise sequence spiralling towards the disc’s centre.

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Keynote: Plasma Astrophysics by chance and vision

M. Goossens  
*CPA, KU Leuven*

In the first part of this talk I shall bore the audience with a brief historical overview of how research in Plasma Astrophysics and Solar physics started and evolved at the University of Leuven from zero over a nucleus to the present Centre for Mathematical Plasma Astrophysics. I shall explain that initially in the early 70s chance played an important role in bringing me in contact with MHD and plasma physics. Subsequently, influenced by several people, some of whom I suspect are not even aware of their contribution, I came to the realisation that MHD and plasma physics are important in many areas of astrophysics, solar physics and magnetospheric physics and that deep mathematical analysis is often needed to understand the complicated behaviour of plasma systems. This vision led to CPA in January 1992. The subsequent history of CPA will be discussed very briefly. The role of PhD students, postdocs, visiting professors and international collaborators will be highlighted. In this part of the talk undue emphasis will be given to the role I played in this process.

In the second part of the talk I shall shift from history to science. I shall present a selection of fun stuff on MHD waves that I really enjoyed working on. As always I shall refrain myself from being naughty, but I shall definitely try to be provocative and controversial.

“I’m disrupting the learning process and I love it.” (Bart Simpson)

“In the end all will be ok. If all is not ok, it is not the end.” (Anonymous).

Comments on Selected Papers of M Goossens

B. Roberts  
*School of Mathematics and Statistics, University of St Andrews*

We give a brief overview of certain papers of M Goossens, highlighting some general aspects and offering some comments from a personal perspective.
Invited Review: Coronal heating – Keeping an open mind

S. Bradshaw
Rice University, Houston

Coronal heating mechanisms have been broadly categorised as either AC or DC in nature; AC being wave-related and DC associated with a gradual build-up and then release of magnetic stress. We do not at present have sufficient evidence in favour of one over the other. It is perfectly feasible that one or both may make a significant contribution, under particular circumstances, to maintaining coronal temperatures above 1 MK. Recent observational diagnostics of the temporal properties of coronal heating have included: measurements the slope of the emission measure (EM) curve from its peak to a temperature of 1 MK; the presence of bulk flows along the line-of-sight with transitions between red- and blue-shifts at temperatures that depend on the properties of the energy release in the observed structures (higher temperatures in active regions than in the quiet Sun); and a tantalising hint of hot (around 10 MK) components in EM reconstructions.

Regardless of whichever mechanism is ‘fashionable’ at any given time, it must be able to reproduce and ultimately explain these observational findings. Furthermore, new observational results concerning the apparent ubiquity of Alfvén waves propagating in the corona has prompted a renaissance in the study of these waves as a potential energy source. I will review all of these observational clues and discuss some of the mechanisms (AC and DC) to which they point.

Invited Review: Observations and simulations of sunspot waves and oscillations

E. Khomenko
Instituto de Astrofisica de Canarias, La Laguna, Tenerife

Waves and oscillations are observed at all layers of sunspot atmospheres, from the photosphere up to the corona. They typically show complex spatial distribution and non-linear behaviour in the upper layers. The nature of these waves is intimately related to the properties of the magnetised atmospheres where they propagate. Correct interpretation of the observed variations in terms of different modes, and understanding of the role of the mode conversion is needed to advance sunspot seismology, helping to recover sub-surface structure of sunspots. In this talk I will summarise recent advances in observations and numerical simulations of sunspot waves from below the photosphere to the chromosphere and corona. I will discuss the efficiency of the mode conversion in different situations, including the conversion to Alfvén waves, as well as observational evidences of these process. Contribution of the MHD wave energy for the heating of the upper atmosphere will be discussed as well.
Invited Review: Drowning in data – The battle for science

R. T. J. McAteer
New Mexico State University, Las Cruces

The last two decades have witnessed a verification of the many expected wave modes in the outer solar atmosphere. Coronal imaging data from SoHO-EIT, TRACE, STEREO, and now SDO all exhibit oscillations indicative of wave modes, and this expanding field of coronal seismology continues to branch out to address issues of energy storage, transfer, and dissipation. However the data volume of SDO had led to new problems – how can a scientist determine which dataset may be of interest, and how can a scientist study that dataset efficiently.

I address three solutions to this problem – the Fast Fourier transform, the wavelet transform, and a Bayesian inference – in searching for and characterising oscillations. Each approach has different strengths and weaknesses. They produce similar results in many cases, but (as seems to always be the case in science), it is where they disagree that we can learn the most interesting information and pose further questions. In the larger scheme, I will place this review in the context of advanced image processing techniques, the SDO Feature Finding Team project, and advances in GPU calculations.

Invited Review: BUKS2012 – A year in review

G. Verth
SP²RC, University of Sheffield

The latest high spatial/temporal resolution spaceborne (Hinode, SDO), balloon (IMax) and ground based instruments (CoMP, ROSA, CRISP) continue to provide exciting new discoveries regarding the role MHD waves play in the dynamics and heating of the solar atmosphere. Concurrently, theorists have been developing MHD models that can help provide the correct physical interpretation of observed wave modes and provide useful insight into what governs their specific characteristic properties. In this review I will highlight notable recent advances in both theory and observation of MHD waves in the Sun’s atmosphere.
Invited Review: Formation and propagation of coronal shock waves

B. Vrsnak
Hvar Observatory, Faculty of Geodesy, Zagreb

Explosive expansion of coronal structures associated with CME/flare eruptions creates large-scale large-amplitude waves and shocks in the solar corona. These global disturbances are observed as EUV coronal waves, chromospheric Moreton waves, type II radio bursts, and sharp fronts in coronagraphic images of CMEs. In this review, the observational characteristics of these wave signatures are related to theoretical considerations.

From the observational point of view, regarding the low-coronal signatures of the disturbances (EUV waves), the most favourable initiation process is the impulsive lateral expansion of CME flanks at the early phase of the eruption. Thus, the most suitable formation mechanism is the accelerating 2.5-D piston that creates a large-amplitude magnetosonic wavefront, which steepens into a shock due to a nonlinear evolution of the wave. In this phase the wave amplitude increases, the leading edge sharpens, and the phase-velocity increases. After the lateral expansion of the CME stops, the disturbance continues to move as a freely propagating simple-wave: the wave profile broadens, the amplitude decreases, phase-speed decreases, and a propagating rarefaction region forms in the wake of the wavefront.

The formation of the disturbance segments closer to the nose of the erupting arcade is similar to that at its flanks, and it results in the excitation of type II radio burst and appearance of bright front in EUV filtergrams and white-light coronagraphic images. However, these wave segments stay continuously driven by the eruption and can survive all the way to 1 AU and beyond. A very favourable condition for long-distance propagation of the shock is decreasing ambient density and magnetosonic speed, which can even lead to an increase of the wave amplitude and Mach number. Finally, it is illustrated how the observational/theoretical analysis of the evolution of coronal waves and shocks can be applied to diagnostics of the solar atmosphere and how it can help in space weather forecasting.

This work has received funding from European Physical Society and the European Commission FP7 Project eHEROES (284461, 2012-2015).
Automated detection of oscillations in the Solar atmosphere using Pixelize Wavelet Filtration

S. A. Anfinogentov, R. A. Sych
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The modern orbital solar observatories (SOHO, TRACE, STEREO and especially SDO) provide facilities for studying oscillations in solar atmosphere. Usually manual detection is used for finding oscillating areas. However this way is inefficient for very large data volume which is produced by Solar Dynamics Observatory (SDO). It is quite important to develop a fast and robust algorithm of automated oscillations detection.

We present the new approach for automated detection of oscillations and waves in solar atmosphere which is based on Pixelize Wavelet Filtration Method. Our algorithm is fully automated. It detects oscillation sources in temporal image sequences and finds out their properties. It can detect oscillations both with known and unknown period. The algorithm was tested both on model data and on real observation in EUV and microwave emission. The test’s result is that our method reliably detects oscillation sources almost without false detection and it is fast enough for the real time processing of the SDO/AIA data.

In particular, application of this method allowed us to establish a phenomenological relationship between oscillations in sunspots and the periodicity in the powerful energy releases. The analysis of the microwave emission recorded by the Nobeyama Radioheliograph at 17 GHz shows a gradual increase in the power of the 3-min oscillation train in the sunspot associated with AR 10756 before flares in this AR.

Line-of-sight geometrical effects on intensity perturbations by sausage modes

P. Antolin, T. Van Doorsselaere
CPA, Leuven

Interpreting observations is far from a trivial matter. It not only relies on our knowledge of what we consider there to be the correct physics and on our ability to apply a theoretical concept to a specific physical environment, but also on the response of the measuring instrument to the physical state of the latter. Translating a numerical simulation output to the observational scenario is a very delicate procedure and has become a field by itself, known as forward modelling. A clear example of this problem is the diagnostics of MHD waves, which often leads to several interpretations and heated debates in the solar community.

In this talk we would like to demonstrate the several issues introduced by considering line-of-sight geometrical effects. We take a cylindrical tube simulating a loop in a low-$\beta$ coronal environment with an optically thin background, and let it oscillate with the sausage mode. Taking into account the spatial, temporal and spectral resolution of the instrument we make a parametric study of the effects of the line-of-sight angle on the intensity, Doppler shift, width and non-Gaussianity of the spectral emission, for the sausage mode. We predict periodic intensity variations (below 10%) decreasing with spatial resolution and wavelength of the oscillation, for a relatively broad range of viewing angles. Periodic non-gaussianities in line emission can be observed even with spatial resolutions of a few tube radiuses, irrespective of the wavelength and of viewing location along the tube. Furthermore, periodic blueshift and redshift excursions are expected when observing with spatial resolution of up to 1 tube radius and for a wide set of viewing angles.
Dislocations in MHD waves

A. Lopez Ariste
THEMIS/CNRS, La Laguna

Dislocations (singularities in the phase of a wave) were first found and described by Nye & Berry (1974) in ultrasound waves. After being also found in light, associated to orbital angular momentum, they have been the centre in the last years of a growing research activity involving many results and applications. I will explore dislocations in MHD waves propagating in isothermal stellar atmospheres. As a first result in this simple cases magnetoacoustic waves can carry vortices, and these dislocations can be associated to kink modes if their charge is 1, flute modes if their charge is 2, etc. Observations of waves in sunspots present vortex dislocations with charge 1 that can be associated to kink modes. As a first application of these preliminary results I will discuss the relative presence in the observed waves of sausage, kink and higher modes as revealed by the observed dislocations.

Transversal oscillations of emerging coronal loops

I. Ballai
SP²RC, University of Sheffield

We investigate the nature of transversal kink oscillations of loops emerging through the solar corona and how can oscillations be used to diagnose the plasma parameters and the magnetic field. In particular, we aim to analyse how the temporal dependence of the loop length (here modelling the emergence) will affect the $P_1/P_2$ period ratio of transversal loop oscillations. Due to the uncertainty of the loop's shape through its emergence, we discuss separately the case of the loop that maintains its initial semi-circular shape and the case of the loop that from a semi-circular shape evolve into a semi-elliptical shape loop. Using the WKB approximation we find approximate values for periods and their evolution, as well as the period ratio. For small values of time (near the start of the emergence) we can employ a regular perturbation method to find approximate relations for eigenfunctions and eigen-frequencies. The change in the period due to the increase in the loop's length is more pronounced for those loops that emerge into a more structured (or cooler corona). The deviation of periods will have significant implications in determining the degree of stratification in the solar corona.
Towards Earth-like worlds: Identifying and removing stellar jitter due to granulation and Solar-like oscillations

H. Cegla, C.A. Watson
Queen’s University Belfast

Space-based, photometric transit surveys have moved us into a new era of exoplanet discovery, identifying thousands of planetary candidates. However, radial velocity (RV) follow-up is mandatory for most systems to measure the candidate’s mass and thereby confirm its planetary nature. To do this for low-mass planets typically requires cm s\(^{-1}\) RV precision. Unfortunately, astrophysical noise sources (or stellar jitter) due to spots, plages, granulation and stellar oscillations, for example, become an issue at the m s\(^{-1}\) level. These phenomena alter the shape of the stellar absorption lines, injecting spurious or systematic RV signals that may mask or mimic planetary signals. As such, active stars are not ideal candidates for RV follow-up and are thus often left out of planet surveys.

Unfortunately, even ‘quiet’ stars (those with little or no activity) exhibit jitter due to granulation and stellar oscillations. For this small-scale jitter, the currently implemented removal technique rests on adapting observational strategies to average out such noise. However, this technique is observationally intensive and does not provide information on the nature of jitter. We aim to go beyond these previous removal techniques, as such we turn to the Sun. Currently, the Sun is the only available test-bed for studying stellar jitter at such high precision. We present our techniques to explore jitter due to granulation through the use of sophisticated 3D magnetohydrodynamical simulations of the Sun. We also investigate the effects due to oscillations that arise from our simulations of solar granulation. In addition, we present the identification of an entirely new source of stellar jitter, hitherto unrecognised, that could impact the RV follow-up and confirmation of low-mass terrestrial planets and Earth-like worlds.

Nonlinear cascade of long-wavelength torsional Alfvén waves

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2. CFSA, University of Warwick
3. Central Astronomical Observatory, Russian Academy of Sciences

We have studied the nonlinear phenomena accompanying long-wavelength torsional (Alfvén) waves in solar and stellar coronae. The analytical method is based on the second order thin flux-tube approximation of Zhugzhda, describing MHD perturbations of a straight axisymmetric, untwisted and non-rotating magnetic flux-tube, in application to e.g. coronal jets, loops. The aim was to study the compressible perturbations nonlinearly induced by long-wavelength torsional waves with small, but finite amplitude and also study the back reaction of the these perturbations on the torsional Alfvén wave itself. These results are compared to the case for the shear Alfvén wave, showing how the plasma beta would affect the shear Alfvén wave and not the torsional Alfvén wave. In addition, taking into account spectral techniques, the efficiency of the parallel nonlinear cascade of energy in torsional and shear Alfvén waves has been compared. The main result of this work is to emphasise that previous one-dimensional models in application to coronal heating and wave acceleration, which use shear Alfvén waves instead of torsional Alfvén waves, over-estimate the efficiency of these processes and need to be revised.
The new method of 3D magnetic field reconstruction based on frequency filtering of torsional Alfvén waves

V. Fedun
SP²RC, The University of Sheffield

By implementing a full nonlinear 3D MHD numerical simulation with a realistic vortex driver, we demonstrate how the plasma structure of chromospheric magnetic flux tubes can act as a spatially dependent frequency filter for torsional Alfvén waves. Importantly, for solar magnetoseismology applications, this frequency filtering is found to be strongly dependent on the magnetic field structure of the flux tube. With reference to an observational case study of propagating torsional Alfvén waves produced in Hα using spectroscopic data from the Swedish Solar Telescope (SST), we demonstrate how the observed two-dimensional spatial distribution of maximum power Fourier frequency shows a strong correlation with our forward modelling. This opens the possibility of beginning an era of chromospheric magnetoseismology, to complement the more traditional methods of mapping the magnetic field structure of the solar chromosphere.

What can be learned from the seismology of coronal loops using a handful of eigenfrequencies?

R. Jain¹, B. W. Hindman²
1. SP²RC, University of Sheffield
2. JILA, University of Colorado, Boulder

Observational evidence suggests that coronal loops exhibit transverse oscillations. These have been used as diagnostic tools to understand the structure of the coronal loops. The form of magnetic field and density is assumed inside and outside the modelled coronal flux tube and the eigenfrequencies are calculated from the kink tube wave equation which is a Sturm-Liouville problem. However, since neither the magnetic field strengths nor the density can be observed independently with great accuracy inside the coronal tubes, the most one can learn from this approach, is how the kink tube speed varies as a function of height. In this talk we suggest a methodology to obtain information on the fractional changes in the kink speed relative to a reference model by inverting the integral equations that relate the eigenfrequencies to the loop properties.
The Source of three-minute magneto-acoustic oscillations in coronal fans

D. B. Jess  
*Queen's University Belfast*

We use images of high spatial, spectral, and temporal resolution, obtained using both ground- and space-based instrumentation, to investigate the coupling between wave phenomena observed at numerous heights in the solar atmosphere. Analysis of continuum images reveals small-scale umbral intensity enhancements, with diameters ~0.6'', lasting in excess of 30 min. Intensity oscillations of ~3 min are observed to encompass these photospheric structures. Simultaneous chromospheric velocity and intensity time series reveal an out-of-phase behaviour, implying the presence of (magneto)acoustic oscillations. An average blue-shifted Doppler velocity of ~1.5 km s\(^{-1}\) confirms the presence of upwardly-propagating slow-mode waves in the lower solar atmosphere. Propagating oscillations in EUV intensity are detected in simultaneous coronal fan structures, with a periodicity of 172±17s, and a propagation velocity equal to 45±7 km s\(^{-1}\). The coronal fans are seen to anchor into the photosphere in locations where large-amplitude umbral dot oscillations manifest. Derived kinetic temperature and emission measure time series display prominent out-of-phase characteristics, and when combined with the previously established sub-sonic wave speeds, we conclude that the observed EUV waves are the coronal counterparts of the upwardly-propagating (magneto)acoustic slow-modes detected in photospheric umbral dots.

Simulation of chromospheric and coronal waves generation

Y. Kato  
*Institute of Space and Astronautical Science, Japan*

Using radiation magnetohydrodynamic (RMHD) simulations of the solar atmosphere comprising the layers from the upper convection zone to the lower corona, we investigate the propagation of longitudinal slow modes which are excited within the magnetic flux concentrations by the convective downdrafts in the immediate surroundings of magnetic elements. We call this the magnetic pumping process. We find that such slow modes travel along the magnetic flux concentration in the upward direction, develop into a shock wave in chromospheric heights, and propagate further through the transition region. We report on how much energy is deposited by propagating shock waves through the transition region and we discuss on the dissipation process above the photosphere within the magnetic flux concentration.
Tracking magnetic bright point motions throughout the Solar atmosphere

P. Keys
Queen’s University Belfast

The convective cell pattern of granulation forms a significant feature of the solar surface. The flow of granules affects magnetic flux into the inter-granular lanes creating small magnetic field concentrations with field strengths of the order of a few kilogauss, known as Magnetic Bright Points (MBPs). These small features are ubiquitous across the solar photosphere and are a significant carrier of solar flux. MBPs can act as conduits to transport energy into the upper solar atmosphere through the production of magneto-hydrodynamic waves. Thus, they are an interesting topic for study in solar physics.

Previously, we have performed research on the velocity characteristics and area distributions of these MBPs in the solar photosphere; now we extend that study to include the solar chromosphere. Presented here are the results of a study of MBPs observed in Ca II K, a chromospheric line, which is compared to G-band observations of the solar photosphere for key properties of these MBPs. The data was obtained using the ROSA instrument at the Dunn Solar Telescope. These observations are compared to simulations generated using the MURaM radiative MHD code.

Propagating disturbances in coronal loops: A detailed analysis of propagation speeds

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Quasi-periodic disturbances have been observed in the outer solar atmosphere for many years now. Although first interpreted as upflows (see Schrijver et al. 1999), they have been widely regarded as slow magnetoacoustic waves, due to observed velocities and periods. However, recent observations have questioned this interpretation as periodic disturbances in Doppler velocity were found to be in phase with the intensity oscillations, suggesting the disturbances could be quasi-periodic upflows.

Here we conduct a detailed analysis of the velocities of these disturbances across several wavelengths using the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO). We analysed 41 examples, including both sunspot and non-sunspot regions of the Sun. We found that the velocities of propagating disturbances (PDs) located at sunspots are more likely to be temperature dependent, whereas the velocities of PDs at non-sunspot locations do not show a clear temperature dependence. We also considered on what scale the underlying driver is affecting the properties of the PDs. Finally, we found that removing the contribution due to the cooler ions in the 193Å wavelength suggests that a substantial part of the 193Å emission of sunspot PDs can be contributed to the cool component of 193Å.
Transverse Oscillations in Chromospheric Mottles

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3. National Observatory, Athens

A number of recent investigations have revealed that transverse waves are ubiquitous in the solar chromosphere. The vast majority of these have been reported in limb spicules and active region fibrils. We investigate long-lived, quiet Sun, on-disk features such as chromospheric mottles (jet-like features located at the boundaries of supergranular cells) and their transverse motions.

The observations were obtained with the Rapid Oscillations in the Solar Atmosphere (ROSA) instrument at the Dunn Solar Telescope. The dataset comprises simultaneous imaging in the $H_\alpha$ core, Ca II K, and G band of an on-disk quiet Sun region. Time-distance techniques are used to study the characteristics of the transverse oscillations. We detect over 40 transverse oscillations in both bright and dark mottles, with periods ranging from 70 to 280s, with the most frequent occurrence at ~165s. The velocity amplitudes and transverse displacements exhibit characteristics similar to limb spicules. Neighbouring mottles oscillating in-phase are also observed. The transverse oscillations of individual mottles are interpreted in terms of magnetohydrodynamic kink waves. Their estimated periods and damping times are consistent with phase mixing and resonant mode conversion.

Wave leakage and resonant absorption in a loop embedded in a coronal arcade

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Universitat de les Illes Balears, Mallorca

We investigate the temporal evolution of impulsively generated perturbations in a potential coronal arcade with an embedded loop. As the initial configuration we consider a coronal loop, represented by a density enhancement, which is unbounded in the ignorable direction of the arcade. The linearized time-dependent magnetohydrodynamic equations have been numerically solved in field-aligned coordinates and the time evolution of the initial perturbations has been studied in the zero-$\beta$ approximation. For propagation constrained to the plane of the arcade, the considered initial perturbations do not excite trapped modes of the system. This weakness of the model is overcome by the inclusion of wave propagation in the ignorable direction. The inclusion of perpendicular propagation produces two main results. First, damping by wave leakage is less efficient because the loop is able to act as a wave trap of vertical oscillations. Second, the consideration of an inhomogeneous corona enables the resonant damping of vertical oscillations and the energy transfer from the interior of the loop to the external coronal medium.
The effect of curvature on the slow modes of dipped filament magnetic structures

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2. Instituto de Astrofísica de Canarias, La Laguna

Longitudinal oscillations consisting of periodic motions of prominence material along a filament axis have been reported. From the theoretical point of view, this would correspond to slow magneto-hydrodynamic oscillations. Here we consider the effect of curvature (forming a dip) on the hydrodynamical equations that govern the slow modes and solve them for different profiles along the thread. Our results confirm that for typical values of the thread density, width and curvature radius, \( R \), the mode of oscillation has a frequency close to \( \sqrt{g_0/R} \) where \( g_0 \) is the solar surface gravity, and the thread oscillates almost as a solid body, in accordance with the observational evidence. We conclude that the observed oscillations occur because threads reside in magnetic concavities with large radii of curvature. Our model also yields a powerful seismological method for constraining the coronal magnetic field strength and radius of curvature at the thread locations.

Generation of quasi-periodic waves and flows in the Solar atmosphere by oscillatory reconnection

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2. SP²RC, The University of Sheffield

We investigate the long-term evolution of an initially buoyant magnetic flux tube emerging into a gravitationally stratified coronal hole environment and report on the resulting oscillations and outflows. We perform 2.5-dimensional nonlinear numerical simulations, generalising the models of McLaughlin et al. (2009) and Murray et al. (2009). We find that the physical mechanism of oscillatory reconnection naturally generates quasi-periodic vertical outflows, with a transverse/swaying aspect. The vertical outflows consist of both a periodic aspect and evidence of a positively directed flow. The speed of the vertical outflow (20–60 km s\(^{-1}\)) is comparable to those reported in the observational literature. We also perform a parametric study varying the magnetic strength of the buoyant flux tube and find a range of associated periodicities: 1.75–3.5 minutes. Thus, the mechanism of oscillatory reconnection may provide a physical explanation to some of the high-speed, quasi-periodic, transverse outflows/jets recently reported by a multitude of authors and instruments.
3D numerical simulations of coronal loop oscillations

I. De Moortel, D. J. Pascoe

School of Mathematics and Statistics, University of St Andrews

Three-dimensional numerical simulations are performed of the interaction of a fast MHD wave with a coronal loop. The loop itself is modelled as a three-dimensional density enhancement (with a finite plasma beta) within a two-dimensional magnetic arcade. Previous results (De Moortel & Pascoe 2009), found a period which differed substantially from the expected value for a straight flux tube (leading to a mismatch between the “traditional” seismological estimate and the actual value of the magnetic field strength). Here we present a parameter study which systematically examines the influence of the loop curvature, the density ratio, and the aspect ratio of the loop on the oscillation period.

Phase relations for seismology of photospheric flux tubes

M. Moreels

CPA, KU Leuven

We assess the possibility of photospheric seismology with the use of magnetohydrodynamic waves. Recently MHD waves have been observed in the photosphere using the Solar Optical Telescope (Fujimura and Tsuneta 2009), the Rapid Oscillations in the Solar Atmosphere instrument (Morton, Erdelyi, Jess et al. 2011 and Jess, Pascoe et al. 2012) and the Swedish Solar Telescope (Jess et al. 2009). Here we investigate if these observations allow us to calculate non-observable quantities of the flux tubes in the photosphere, such as the vertical wave number.

We use a straight cylinder as a model for the flux tube. The plasma is uniform both inside and outside the flux tube with a possible jump at the boundary, the magnetic field is directed along the flux tube. We calculate analytic expressions for the velocity, intensity and magnetic field perturbations for both propagating and standing waves in the flux tube. Using these analytic expressions we can calculate the phase differences and phase relations between the velocity, the intensity and the magnetic field. These can then be used to identify the type of magnetohydrodynamic waves in the photosphere. The amplitude ratios of the velocity, the intensity and the magnetic field can be used to seismologically determine physical parameters of the photospheric flux tube.
Chromospheric jets around the edges of sunspots: waves and upflows

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Evidence is beginning to be put forward that demonstrates the role of the chromosphere in supplying energy and mass to the corona. So far, this has been in the form of observations of fast moving ($v > 50 \text{ km s}^{-1}$) jet events referred to Type-II spicules seen in chromospheric lines before appearing in coronal EUV lines. This behaviour has typically been reported in coronal hole and plage regions. In general, the study of chromospheric jets has revolved around coronal holes, plage and quiet Sun regions. The jets in each of these magnetically different regions display diverse behaviour. We aim to assess the role of chromospheric jets in active region dynamics. Using a combination of the Hinode/SOT Ca II H and TRACE 1550Å and 1600Å filters we examine chromospheric jets situated at the edge of a sunspot. Analysis reveals a near continuous series of jets, which raise chromospheric material into the low corona above a sunspot. The jets have average rise speeds of $30 \text{ km s}^{-1}$ and a range of 10–100 km s$^{-1}$. Enhanced emission observed at the jets leading edge suggests the formation of a shock front. Increased emission in TRACE bandpasses above the sunspot and the disappearance of the jets from the Ca II filter suggests that some of the chromospheric jet material is at least heated to $\sim0.1 \text{ MK}$. The evidence suggests that the jets could be a mechanism that provides a steady, low-level heating for active region features.

Concurrent wave modes in the solar chromosphere

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Observations have revealed that the chromosphere and corona support ubiquitous transverse waves. The transverse waves were observed in the chromosphere via Ca II H limb observations of spicules, which are associated with open magnetic structures, e.g. magnetic funnels. However, open magnetic structures are thought to occupy only a small percentage of the atmosphere at chromospheric heights (1–5%). Here we present observations of the on-disk quiet Sun chromosphere using the $\text{H}_\alpha$ filter on the ROSA imaging system and images from Hinode. The $\text{H}_\alpha$ chromospheric spectral line reveals the true upper chromosphere when viewed on-disk. It has been demonstrated that in the quiet Sun that $\text{H}_\alpha$ observes mainly closed magnetic structures within the chromosphere. We resolve ubiquitous transverse motions in these closed magnetic structures. Further to this, we are also able to observe fast propagating, periodic intensity disturbances. These are identified with magnetic structures showing periodic changes in width suggesting we are observing the fast sausage mode. We present the measured properties of both waves, estimates for their energy and discuss the implications of the observations for heating of the solar atmosphere.
Dynamics of the solar corona from observations of EUV coronal jet

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Jets are collimated and fast ejection of plasma observed at Extreme UltraViolet (EUV) wavelengths. We present observations of them which were detected with the STEREO spacecraft using data from the EUVI (Extreme Ultra-Violet Imager) and COR1 (CORonagraph) telescopes. Jets were observed during the solar minimum from 2007 to 2008 at polar and mid-low latitudes within coronal holes (Nisticò et al., Solar Phys., 259, 87, 2009; Nisticò et al., Ann. Geophys., 28, 687, 2010).

From observations of jets at polar latitudes, we have found a systematic change in the jet Position Angle (PA) when going from the EUVI FOV (Field Of View) at 1 R to the COR1 FOV at 2 R. This change in PA is consistent with the jet motion along the Sun dipolar magnetic field, confirming that the polar corona is a low-β plasma. However, this magnetic deflection is found to be larger at the North pole than at the South pole, as demonstrated by other datasets (Erdos & Balogh, JGR, 710, 1806, 2010; Virtanen & Mursula, JGR, 115, A09110, 2010). We made temperature measurements with the technique of the filter ratio at EUV wavelengths (Nisticò et al., Adv. Space Res., 9, 1490, 2011) in order to understand the physical mechanism at the basis of their origins and for comparison with existing models and numerical simulations. Moreover, with the assumption that jets can create fast shocks, we show by mean of test-particle simulations that perpendicular shocks in the solar corona are a reliable mechanism for the more than mass proportional heating of heavy ions like O5+, as inferred from SoHO/UVCS measurements (Nisticò & Zimbardo, Adv. Space Res., 2, 408, 2012).

Determining normal mode features from numerical simulations using CEOF analysis

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CEOF analysis in time domain allows to obtain the spatial and temporal properties of standing oscillations and propagating waves in a multivariate data set. It has been successfully used to analyse geophysical and astrophysical data. Here it is put forward as a tool to determine the spatial structure and frequency of normal modes from the results of numerical simulations. Test cases, for which the normal mode properties are known, are studied to examine the performance of CEOF analysis. Then, this technique is also applied to numerical simulations whose respective normal modes are not available.
Numerical simulations of vertical kink oscillations of a solar coronal loop with field aligned flows

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We study vertical kink oscillations in solar coronal loops, considering field aligned flows inside the loops as well as in the surrounding plasma. We focus on the 2D numerical model of a straight slab to investigate the excitation and attenuation of the impulsively triggered kink waves. A flow of the order of the observed flows detected by SOT/Hinode is applied in our model. We vary the inhomogeneity of the longitudinal flow in longitudinal or transverse direction. We find that relaxing the assumption of the limited flows within the loops enhances damping. The damping rate is more sensitive to the transverse profile than to the longitudinal profile of the longitudinal inhomogeneous flow. We further notice that extending the flow pattern beyond the loop enhances the strength of the shock associated with slow magnetoacoustic waves, recognised as an addition feature in the numerical simulation.

Spatial damping of propagating kink waves

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Observations have revealed ubiquitous transverse velocity perturbation waves propagating in the solar corona. We perform 3D numerical simulations of footpoint-driven transverse waves propagating in a low beta plasma. When density structuring is present, mode coupling in inhomogeneous regions leads to the coupling of the kink mode to the Alfvén mode. The frequency-dependent decay of the propagating kink wave is observed as energy is transferred to the local Alfvén mode. Modest changes in density are capable of efficiently converting energy from the driving footpoint motion to localised Alfvén modes. Thus, realistic transverse footpoint motions will deposit energy to (azimuthal) Alfvén modes in the corona.

Mode coupling is investigated in detail for propagating kink modes as an explanation for the observed wave damping and as a possible seismological tool. The observed strong damping of the Doppler shift oscillations indicates the presence of wide inhomogeneous layers at the edges of the loops. Our simulations (backed up by analytical calculations) show that in this regime, the traditional $\exp(-z/L)$ damping rate no longer applies. Hence, care has to be taken when seismologically inferring damping lengths from the observed oscillations. In addition, taking into account line-of-sight integration of multiple loops supporting transverse oscillations, we show that the energy budget present in the 3D coronal volume could be substantially higher than the energy budget derived from the observed Doppler shift oscillations.
Oscillations in open loop structures

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One of the important applications of observing different wave modes in the solar atmosphere is coronal seismology, that allows us to determine some of the physical properties of the source which are difficult otherwise. However, it is extremely important to identify the wave mode observed. Quasi-periodic propagating disturbances, often observed in the active region fan loops, were studied extensively both observationally and theoretically and were thought to be signatures of slow magneto-acoustic waves based on several observed properties. Recent observations suggest that they can also be due to quasi-periodic high speed upflows and do show enhanced blue wing emission when observed spectroscopically. We studied a few open loop structures in the solar corona, both on-disk and off-limb, using images from AIA/SDO in different temperature channels. We also use the co-temporal spectroscopic observations from EIS/Hinode for one particular region. Propagating disturbances with multiple periodicities are observed. Also, the disturbances with longer periodicities are observed to travel farther. We discuss some of these observed properties which may help to identify the nature of these disturbances.

Nonlinear oscillations of coronal magnetic loops

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We present the first analytical study of the effect of nonlinearity on coronal magnetic loop kink oscillations. We model a coronal loop as a straight magnetic tube of constant radius $R$ and length $L$ with its foot points frozen in the dense photospheric plasma. The plasma density varies along the loop and takes different values inside and outside the loop, but it does not vary in the radial direction both inside and outside. It is assumed that this longitudinal variation is sufficiently strong, so that the ratio of frequencies of the first overtone and fundamental harmonic is sufficiently different from the canonical value of 2. In addition, we assume that the oscillation amplitude is sufficiently small, so we can look for the solution to the problem in the form of expansion in power series with respect to the dimensionless amplitude of the loop oscillation. We found that the main nonlinear effect is the phase shift of the oscillation. As an example we consider nonlinear oscillation of a tube with the kink speed that is a quadratic polynomial of the distance along the loop.
Numerical modelling of the solar photosphere: bridging theory and observations

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Understanding the physical processes in the interconnected solar interior and atmosphere requires realistic numerical modelling of these solar regions as well as detailed radiative diagnostics of the simulated solar models. This diagnostics allows us not only to validate and improve numerical models and, thus, our knowledge about the physics of the Sun, but also suggests an attractive possibility to predict the observational representation of various processes in the solar plasma and therefore to develop the observational strategies for the solar observations. In my talk, I will discuss the methods and techniques of realistic solar numerical modelling and radiative diagnostics. I will demonstrate few examples on how advanced solar modelling can be applied to studies of waves, flows and vortices in the solar interior and the photosphere. By computing artificial images of the simulated solar models in different wavelengths and positions at the solar disk, I will demonstrate a link between the processes in the solar plasma and the spectropolarimetric parameters of the solar radiation in the simulated models. These simulated observations will also be discussed in terms of modern observational technologies.

Alfvénic kink waves in partially ionized magnetic flux tubes

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Magnetohydrodynamic (MHD) waves are ubiquitous in the solar atmosphere. Alfvénic kink waves are a particular class of MHD wave. In the fully ionized corona, TRACE observations of loop transverse oscillations have been interpreted as standing kink waves, while CoMP observations of running disturbances have been related to propagating kink waves. Resonant absorption, caused by plasma inhomogeneity in the transverse direction to the magnetic field, is an efficient damping mechanism for these waves. However, Alfvénic kink waves are also observed in chromospheric spicules and in solar prominences. Due to their relatively cool temperature, chromospheric and prominence plasmas are only partially ionized. Here we investigate the impact of partial ionization on the propagation and damping of Alfvénic kink waves in magnetic cylinders. We use the two-fluid approach in which ions and electrons are considered together as an ion-electron fluid, i.e., the plasma, while neutrals form another fluid that interacts with the plasma by means of collisions. We obtain a general dispersion relation for MHD waves and derive analytic approximations for Alfvénic kink waves in particular limits. We recover the wave frequencies for a fully ionized plasma when the ion-neutral collision frequency is much lower that the wave frequency. As the collision frequency increases the two fluids become more coupled. For realistic collision frequencies, plasma and neutrals behave as a single fluid with an effective density corresponding to the sum of densities of both fluids. The wave frequencies are therefore lower than in the fully ionized case and depend on the ionization degree. In addition, we find that the contribution of resonant absorption to the damping is inversely proportional to the frequency as in the fully ionized case, while the contribution of ion-neutral collisions is inversely proportional to the square of the frequency.
Temperature and spatial stratification of the sources of EUV emission oscillations above sunspots

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We present the study of wave and oscillatory processes above the sunspot NOAA 11131 on the 8th of December 2010 in the EUV band with the use of SDO/AIA data. The spatial structure of the sources for oscillation with different distinct periods was identified for the first time at 10 different wavelengths. At the photospheric heights the 5.6 mHz oscillation source has a circular shape, filling in the umbra. In the transition region this oscillations are seen as waves propagating to the umbra-penumbra boundary. The wave fronts have a helical shape. The centre of the helix located near the centre of the sunspot umbra. In the corona we observe the formation radially extended fine structures over the penumbra, corresponding to the wave propagation channels, which originate the footpoints of coronal magnetic flux tubes. Individual tubes are characterised by specific frequencies of the propagating waves. At the transition region the sources of longer-period oscillations have the ring shape where the oscillation power has a radially patchy distribution. The main oscillation frequencies decrease with the distance from the sunspot centre gradually from 5.6 mHz in the umbra down to 0.8 mHz in the penumbra. We developed a new method for obtaining the 3D height-spatial structure of magnetic tubes in the sunspot atmosphere. The method is based on dynamics of extrapolated magnetic surfaces (SDO/HMI magnetograms) and PWF technique. A possible interpretation of the obtained results is connected with the model of the projection helicity effect of spaghetti-like magnetic flux tubes with different spatial localisation, field lines inclination and the cut-off frequency effect. The flux tubes act as wave-guides of the slow magnetoacoustic waves, responsible for the observed oscillations.

Study of the three-dimensional shape and dynamics of coronal loops observed by Hinode/EIS

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We study plasma flows along selected coronal loops in NOAA Active Region 10926, observed on December 3, 2006 with Hinode EUV Imaging Spectrograph (EIS). From the shape of the loops traced on intensity images and the Doppler shifts measured along their length we compute their three-dimensional (3D) shape and plasma flow velocity using a simple geometrical model. This calculation was performed for loops visible in the Fe VIII 185Å, Fe X 184Å, Fe XII 195Å, Fe XIII 202Å, and Fe XV 284Å. Most cases the flow is unidirectional from one footpoint to the other but there are also cases of draining motions from the top of the loops to their footpoints. Our results indicate that the same loop may show different flow patterns when observed in different spectral lines, suggesting a dynamically complex rather than a monolithic structure. We have also carried out magnetic field extrapolations using SOHO/MDI magnetograms, aiming toward a first-order identification of extrapolated magnetic field lines corresponding to the reconstructed loops. In all cases, the best-fit extrapolated lines exhibit left-handed twist (\(\alpha<0\)), in agreement with the dominant twist of the region.
EUV Doppler shifts as a signature of transient heating in the Solar corona

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Hinode/EIS observations of an active region are presented. Intensity and Doppler velocity maps for different emission lines are constructed. Consistent with previous results, the Doppler velocities near the footpoints of coronal loops appear to be blue shifted for emission lines with temperatures above 1 MK. The gradual transition from blue shifts at temperatures above 1 MK to red shifts at temperatures below 1 MK is addressed through numerical modelling of loop dynamics. The simulation results are converted into synthetic EIS observations and compared with the actual measurements. Persistent blue and red shifts observed in EUV lines are interpreted as a signature of repetitive transient heating in the solar corona on a time scale of a few minutes. No assumptions about the nature of the heating process are made.

Rayleigh-Taylor unstable modes in filament threads

J. Terradas, R. Oliver, J. L. Ballester

Short-lived horizontal threads lying parallel to the photosphere are thought to be the building blocks of many solar filaments. The possible link between Rayleigh-Taylor instabilities and thread lifetimes is investigated. We calculate the eigenmodes of a thread modelled as a Cartesian slab under the presence of gravity and using the incompressible assumption for the magnetohydrodynamic (MHD) perturbations. The system allows a mode that is always stable, independently of the value of the Alfvén speed in the thread. On the contrary, the slab model permits another mode that is unstable and localised at the lower interface when the Alfvén speed is low. The growth rates of this mode can be very short, of the order of minutes for typical thread conditions.
Linear & nonlinear MHD wave behaviour and coupling about 3D magnetic null points

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Theory, observations and simulations of MHD waves in the corona are typically interpreted in terms of the Fast/Slow magnetoacoustic and Alfvén modes. Here we consider MHD wave behaviour about 3D magnetic null points. The magnetic field eccentricity parameter is varied to achieve topologies ranging from azimuthal symmetry (essentially 2.5D) to fully 3D field structures, to assess the suitability of the concepts and terminology of Fast, Slow and Alfvén waves in full 3D and investigate how wave dynamics differs from the 2.5D regime.

Through the use of a field line/flux based curvilinear coordinate system, linearly pure Alfvén and Fast waves are generated about null points in numerical simulations using LARE3D. The transient behaviour in the linear regime is found to be consistent with 2D results, and the results are in good agreement with the WKB approximation. In the nonlinear regime, our novel coordinate system allows isolation of the constituent modes and an investigation into the nature of their coupling in 3D. We find that coupling between the Fast wave and Alfvén wave due to 3D geometry is absent as both a linear and nonlinear effect. Additionally, we observe non-linear longitudinal perturbations along the equilibrium magnetic field, identified as due to the ponderomotive force.

These results are common across null points of varying eccentricity – only the transient linear wave behaviour alters between different nulls due to altered Alfvén speed profiles. We conclude that for our specific 3D model, the concepts and terminology of Fast, Slow, and Alfvén waves are appropriate and that the dynamics of such waves extend into 3D in a manner consistent with the 2D theory.

The formation of the magnetic canopy and its role on the propagation of waves

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We use time series of $H_\alpha$ filtergrams obtained by the Dutch Open Telescope in 5 wavelengths along the line profile together with SOT/SP high resolution magnetograms to analyse the oscillatory phenomena observed in a solar network region. Using wavelet analysis we investigate the oscillatory power distribution in the 2D field-of-view, as well as its vertical distribution and its relation with the fine-scale structure of the chromosphere. Our results show that the power enhancement (power halo) and suppression (magnetic shadow) observed in the network region are directly related to the chromospheric fine-scale structure. We attribute this finding to the interaction between acoustic oscillations and fine scale structures which outline inclined magnetic fields and provide the loci of wave transmission, reflection and refraction. We conclude that these structures are directly related to the formation of the magnetic canopy. Extrapolation of the photospheric magnetic field up to the chromosphere using the current-free assumption and use of the VAL C atmospheric model allows the determination of the height of formation of the magnetic canopy and provides the opportunity to highlight the details of the interaction between acoustic oscillations and the magnetic field.
Uncovering the birth of a coronal mass ejection from two-viewpoint SECCHI observations

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We investigate the initiation and formation of Coronal Mass Ejections (CMEs) via a detailed two-viewpoint analysis of low corona observations of a relatively fast CME acquired by the SECCHI instruments aboard the STEREO mission. The event which occurred on 2 January 2008, was chosen because of several unique characteristics. It shows upward motions for at least four hours before the flare peak. Its speed and acceleration profiles exhibit a number of inflections which seem to have a direct counterpart in the GOES light curves. We detect and measure, in 3D, loops that collapse toward the erupting channel while the CME is increasing in size and accelerates. We suggest that these collapsing loops are our first evidence of magnetic evacuation behind the forming CME flux rope. We report the detection of a hot structure which becomes the core of the white light CME. We observe and measure unidirectional flows along the erupting filament channel which may be associated with the eruption process. Finally, we compare these observations to the predictions from the standard flare-CME model and find a very satisfactory agreement. We conclude that the standard flare-CME concept is a reliable representation of the initial stages of CMEs and that multi-viewpoint, high cadence EUV observations can be extremely useful in understanding the formation of CMEs.
A new paradigm for the solar atmosphere

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Most current solar atmospheric (wave) models rely on the continuum or fluid approximation (Magneto-hydrodynamics, MHD). However, these models cannot explain everything that is observed in the solar atmosphere. They have, e.g., an intrinsic problem to explain coronal heating completely because i) it is clear that the actual heating takes place at length scales much smaller than those on which the (macroscopic) MHD model is justified; and ii) it is obvious that the observed discrepancy between ion and electron temperatures in the corona, as well as iii) the observed large temperature anisotropy in the inner corona ($T_\perp > T_\parallel$) and iv) the observed preferential heating of the heavier ions are beyond the (single!) fluid model!

We therefore argue that a new paradigm is required to describe the dynamics in the solar atmosphere in a self-consistent manner. The alternative approach is based on the multi-fluid and kinetic theories and rely on abundant micro-instabilities and drift waves. We show, with qualitative and quantitative arguments, that the micro-instabilities and drift waves e.g. have the potential to satisfy all coronal heating requirements. Hence, the basic ingredient necessary for the heating is the presence of density gradients in the direction perpendicular to the magnetic field vector. Such density gradients are a source of free energy for the excitation of drift waves. We use only well-established basic theory, verified experimentally in laboratory plasmas. Two mechanisms of the energy exchange and heating are shown to take place simultaneously: one due to the Landau effect in the direction parallel to the magnetic field, and another one, stochastic heating, in the perpendicular direction. The stochastic heating i) is due to the electrostatic nature of the waves, ii) is more effective on ions than on electrons, iii) acts predominantly in the perpendicular direction, iv) heats heavy ions more efficiently than lighter ions, and v) may easily provide a drift wave heating rate that is orders of magnitude above the value that is presently believed to be sufficient for the coronal heating, i.e., $\approx 6 \times 10^{-5}$ J/(m s) for active regions and $\approx 8 \times 10^{-6}$ J/(m s) for coronal holes. This heating acts naturally through well-known effects that are, however, beyond the current standard models and theories.
First observation of a hot, higher harmonic coronal loop oscillation with AIA/SDO

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We present the first observation of a hot, higher harmonic coronal loop oscillation with the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO). This transverse coronal loop oscillation is observed exclusively in the 131Å and 94Å bandpasses, suggesting that the loop plasma is in the range of 9–11 MK. The loop is observed to oscillate between 12:16:09 and 12:50:09 UT after a C4.9 GOES flare and CME eruption on the 3rd November 2010. Furthermore the loop is not observed to cool into the other AIA channels, but just disappears from all bandpasses after approximately 12:50:09 UT.

Time series analysis of the loop oscillation is conducted by taking several cuts at different $s$-distances along the loop, estimating the displacement position of the oscillation and fitting the estimated positions with a damped cosine curve (e.g. White & Verwichte, 2012). The time series analysis revealed a period of $299\pm14 s$ and a damping time of $358\pm111 s$. A clear phase shift of $\approx180^\circ$ suggests we observe a higher order harmonic. The intensity, both along the loop and at different $s$ positions is investigated.

This is an important observation as it is the first example of a higher harmonic transverse loop oscillation that is spatially observed exclusively in the hot AIA channels. Spatial observations of higher order harmonics in coronal loops are extremely rare and we discuss any insights this observation may have for the excitation of these modes.

The phase speed of EUV propagating disturbances: robust measurement, temperature-dependency, and seismological application

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We designed Cross-Fitting Technique (CFT), 2D Coupled Fitting (DCF) and Best Similarity Match (BSM) techniques to measure the apparent phase speed of coronal propagating EUV disturbances in the time-distance plots obtained with AIA and other imaging instruments. The techniques are applied to the analysis of propagating disturbances observed in the coronal fan-structure at active region NOAA11330 on 27 Oct 2012. The average projected propagating speed is measured at $47.6\pm0.6 \text{ km s}^{-1}$ and $49.0\pm0.7 \text{ km s}^{-1}$ for running difference and background-removed and normalised signal respectively, with periods of $179.7\pm0.2 s$ and $179.7\pm0.3 s$.

Time-distance plots with background removal and normalisation are found to be more consistently measured with little effect from the choice of detrending time, while running difference plots are effectively measured with only certain range of selections of lag time. CFT provides reliable measurement on relatively good samples. DCF is very sensitive to the initial guess and is only optimised in measuring one of the parameters. BSM is robust in measuring all samples and very tolerant to image processing and regularisation (smoothing).

We also analysed propagating disturbances in an off-limb fan structure on 06 to 07 Mar 2012. In our preliminary analysis, we found the period is about 8 min, propagating speed is roughly $80 \text{ km s}^{-1}$. The detection length of the disturbances is about 30–50 Mm, much longer than TRACE studies.
Alfvén waves in solar partially ionized plasma: effects of stratification and neutral helium

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Plasma is only partially ionized in the solar lower atmosphere and prominences. The plasma contains mostly neutral hydrogen atoms, but a significant amount of neutral helium atoms is also presented. The presence of neutral atoms leads to the damping of Alfvén waves due to ion-neutral collision. We study the propagation and damping of Alfvén waves through stratified solar atmosphere taking into account the collision of ions with neutral hydrogen and neutral helium atoms. The expression of Cowling diffusion in the presence of two types of neutral species is revised. We found that the helium atoms significantly increase the damping rate in some conditions of partially ionized plasma. The stratification significantly affect the propagation of Alfvén waves as they are mostly trapped in the lower chromosphere. The coronal heating by photospheric Alfvén waves should be considered with caution.

Cut-off wavenumbers in single-fluid MHD

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Alfvén (fast) wave dynamics in resistive single-fluid magnetohydrodynamics shows the presence of cut-off wavenumber i.e. Alfvén (fast) waves with wavenumbers higher than the cut-off value are evanescent. The cut-off wavenumber appears in both, fully and partially ionized plasmas. To point out the reason for the appearance of a cut-off wavenumber, we start with three-fluid equations (with electrons, protons and neutral hydrogen atoms) and make consecutive approximations until the usual single-fluid description is obtained. We solve the dispersion relation of linear Alfvén waves at each step and seek for the approximation responsible of the cut-off wavenumber appearance. The cut-off wavenumber in single-fluid MHD is the result of neglecting the inertial and Hall terms.
Additional abstracts
The following contributions were submitted after the main booklet went to press.

Effect of density stratification on the amplitude profile of slow longitudinal loop oscillations.

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Magnetohydrodynamic (MHD) wave observations have given an important and novel tool to measure fundamental parameters in the magnetically embedded solar atmosphere. Here, spatial magneto-seismology (i.e., distribution of the amplitude profiles) of slow MHD mode oscillations is used to study the longitudinal distribution of density stratification in solar atmospheric loops. Increasing the density stratification in coronal loops causes the anti-node of the first harmonic moves towards the loop footpoints. The shift is larger for greater density stratification. These results are consistent with the results obtained for transversal coronal loop oscillations. The measurement of the anti-node shift of the first harmonic of longitudinal oscillations provides a complementary method of probing the plasma fine structure in the solar atmosphere.

Wave Processes in the Terrestrial Foreshock

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The purpose of current research is to inspect waves modes in the Foreshock, focusing primarily on their contribution to the solar wind's heating mechanism. The dominant aim is to understand how the waves are generated in-situ and the importance of their compressible effects. Using the Cluster Satellite group observations of plasma instabilities have been observed in high resolution and comparisons to theory have been carried out. Multiple data analysis techniques were deployed to test well known observations. The waves were then assessed and sorted into the already pre-established categories for the foreshock.
Hall MHD waves and their interaction with 2D magnetic X-points

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We investigate the role of the Hall term in the propagation and dissipation of waves which interact with 2D magnetic X-points, in order to determine how the evolution of a nonlinear fast magnetoacoustic wave pulse, and the oscillatory reconnection which results from its interaction with a line-tied 2D magnetic X-point, is affected by the inclusion of the Hall term in the generalised Ohm’s law. A Lagrangian remap code (Lare2d) is used to study the evolution of an initial fast magnetoacoustic wave annulus for a range of values of ion skin depth (di) in resistive Hall MHD. In general, the fast wave is coupled to a shear wave and to whistler and ion cyclotron waves. Dispersive whistler effects cause rapid oscillations of the X-point, leading to the creation of magnetic islands and multiple null points under the influence of the Hall term. At later times, competition of local Lorentz and gas pressure forces return the system to a near-equilibrium state. The rate of oscillatory reconnection recovered during this relaxation phase appears to be unaffected by the value of di.

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Resonant damping of kink waves in a time-dependent loop

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Resonant absorption is a popular and viable mechanism to model the twin problems of MHD wave damping in solar coronal structures (e.g. coronal loops or prominences) and the heating of the plasma in the magnetized corona. Earlier modelling applied the concept of resonant absorption of slow and Alfvén waves in stationary plasma where the background equilibrium is time-independent. However, high-resolution observations of the current cohort of solar instruments clearly indicate that often there is a time-dependent plasma behaviour associated with loop oscillations. In this presentation we show the first steps made to address the challenges in the development of resonant MHD wave theory in a time-dependent plasma. Expressions for the decrease in wave amplitude and wave dissipation across the Alfvén resonant point have been found for plasma structures within time-dependent models. This work also aims to show how the wave amplitude across the resonant points changes in time and contributes to the rapid damping of resonantly coupled driven MHD kink waves.