Royal Astronomical Society Specialist Discussion Meeting

MHD oscillations and waves from the photosphere to the corona

10:00-15:30 14 May 2021

Organisers: Jiajia Liu (QUB), Chris Nelson (QUB), Robert Erdélyi (UoS), Mihalis Mathioudakis (QUB)

Oral Talks

10:00-10:05 – Welcome

10:05-10:30 – Invited Talk by Krishna Prasad Sayamanthula, KU Leuven
The nature and properties of compressive oscillations in hot coronal loops

10:30-10:45 - Aishawnnya Sharma, Bahona College
MHD Wave Amplitude modulation in fan loops as observed by AIA/SDO

10:45-11:00 - Iñigo Arregui, Instituto de Astrofisica de Canarias
Bayesian evidence for the nonlinear damping of coronal loop oscillations

11:00-11:15 - Alexander Shukhobodskiy, Leeds Beckett University
Kink Oscillations of Coronal Loops: The Effect of Cooling

11:15-11:30 - Nived Vilangot Nhalil, Armagh Observatory and Planetarium
Understanding the Type-II spicule contribution to coronal loops

11:30-11:35 - Break

11:35-12:00 - Invited Talk by Hui Tian, Peking University
Magnetoseismology for the solar corona: from ~10 Gauss to coronal magnetograms

12:00-12:15 - Marianna Korsos, Aberystwyth University
Oscillatory behaviour of the magnetic helicity flux between the flaring and non-flaring ARs

12:15-12:30 - Richard Morton, Northumbria University
Evidence that resonant absorption/phase mixing are not important for energy transfer in the quiet Sun

12:30-12:45 - Juan Pablo Arcila Maldonado, Universidad Nacional de Colombia
Direct observational indications of wavelike disturbances in MBP tracks

12:45-13:15 – Lunch Break

13:15-13:40 – Invited Talk by Anne-Marie Broomhall, University of Warwick
Solar cycle variations in the excitation and propagation of solar acoustic oscillations

13:40-13:55 – Joseph Scalisi, University of Sheffield
Torsional Alfvén pulses in zero-beta flux tubes

13:55-14:10 – Abhinav Prasad, Indian Institute of Technology, Varanasi (IIT-BHU)
Standing MHD waves in Magnetic Annulus Geometry

14:10-14:25 – Rajab Ismayilli, KU Leuven
Properties of Uniturbulence in incompressible MHD

14:25-14:40 - Noemi Kinga Zsamberger, University of Sheffield

Asymmetric waveguides in the solar atmosphere

14:40-14:45 - Break

14:45-15:00 – Ben Snow, University of Exeter
Mode conversion of two-fluid shocks in an isothermal stratified atmosphere

15:00-15:15 – Julia M. Riedl, KU Leuven
Finding the mechanism of wave energy flux damping in solar pores using numerical simulations

15:15-15:30 - Thomas Howson, University of St Andrews
Magnetic reconnection and the Kelvin-Helmholtz instability in the solar corona

Posters

1. Szabolcs Soós, Eötvös Loránd University
On the oscillatory behaviour of magnetic helicity in flaring and non-flaring solar active regions

Abstracts

The nature and properties of compressive oscillations in hot coronal loops

Krishna Prasad Sayamanthula, KU Leuven

Flare associated hot (> 6 MK) coronal loops often display compressive oscillations with periods on the order of tens of minutes. Their propagation speeds and other physical properties indicate that they are due to standing slow magneto-acoustic waves. Recent high-resolution imaging observations reveal "sloshing" oscillations with largely similar properties except that their spatio-temporal properties do not actually resemble a standing wave. We investigate the relation between these two (possibly) different class of oscillations using multi-wavelength observations. We find a number of interesting new results including evidence for the eventual transformation of sloshing oscillations into a standing wave. Upon comparing the oscillation properties between the two phases, we observe that both the oscillation period and the damping time are larger in the latter phase. We show that this change in oscillation properties is compatible with the slow wave damping due to thermal conduction in the presence of a cooling plasma. Furthermore, we demonstrate that the distinct oscillation characteristics observed in different wavelength channels are indicative of multi-thermal nature of the coronal loop.

MHD Wave Amplitude modulation in fan loops as observed by AIA/SDO

Aishawnnya Sharma, Bahona College

In this talk, We report the observation of amplitude modulations along a fan loop system by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory. The time-distance maps obtained along the fan loops provide clear presence of propagating 3-min intensity disturbances in all the coronal EUV channels except AIA 94 and 335 Å. We determine the nature of the propagating disturbances as slow-magnetoacoustic waves by measuring their phase speeds. The time-distance map at AIA 171 Å, and the light curves at different spatial locations of the map, show an increase and decrease in the amplitude of propagating oscillations over time. Fouriér analysis on the light curves indicates significant powers between oscillations with 2-3 minutes, along with many other smaller peaks between 1-5 minutes. Wavelet analysis shows an increase and decrease of 3-min oscillating power simultaneous to the amplitude variations with time, with a modulation period in the range of 20-30 minutes. Our results present the viability of occurrence of phenomenon like 'Beat' in the solar atmosphere giving rise to the amplitude modulations over time. Our study may provide valuable insights into understanding the behaviour and possible coupling of slow-magnetoacoustic waves propagating along fan loops, and, could be helpful for numerical and analytical modelling of the wave heating of active regions.

Bayesian evidence for the nonlinear damping of coronal loop oscillations

Iñigo Arregui, Instituto de Astrofisica de Canarias

Recent observational and theoretical studies indicate that the damping of solar coronal loop oscillations depends on the oscillation amplitude. In this study, we consider the mechanisms of linear resonant absorption and nonlinear damping due to the development of the Kelvin-Helmholtz instability. We confront their theoretical predictions with observed data in the plane defined by the damping ratio and the oscillation amplitude. The structure of the Bayes factor in this plane shows a clear separation between the regions where the nonlinear damping model is more plausible relative to the linear resonant absorption model and vice versa. There is a close correspondence between the region of highest Bayes factor for the nonlinear damping model and the location of observed data. In an application to a large number of loop oscillation events observed with SDO/AIA, we find that the marginal likelihood for nonlinear damping is larger in 87 out of the 101 studied cases. Among them, positive evidence in support of nonlinear damping is found in 49 cases. Nonlinear damping is a plausible explanation for the observed properties of damped transverse loop oscillations.

Kink Oscillations of Coronal Loops

Alexander Shukhobodskiy, Leeds Beckett University

Kink oscillations of coronal loops have been vastly studied, both observationally and theoretically. It has been shown that the majority of observed driven coronal loop oscillations appear to damp with either exponential, Gaussian profiles or a transition from Gaussian to exponential profile. Different mechanisms have been proposed to be responsible for this. However, some driven oscillations seem to evolve in manners which cannot be modelled with such profiles, with amplification of oscillations even being observed on occasions. Recent research has shown that incorporating the combined effects of coronal loop expansion, resonant absorption, and cooling can cause significant deviations from Gaussian and exponential profiles in damping profiles. That potentially can explain increases in oscillation amplitude through time in some cases. Recent theoretical achievement allows to study kink oscillation of expanding cooling coronal loops. This approach could also allow us to infer some important diagnostic information (such as, for example, the density ratio at the loop foot-points) from the oscillation profile alone, without detailed measurements of the loop and without complex numerical methods. Results suggests that there is existence of correlations between the density ratio at the loop foot-points and the amplitudes and periods of the oscillations. The comparison of results to previous models, namely purely Gaussian and purely exponential damping profiles, through the calculation of $\chi2$ values, finding the inclusion of cooling can produce better fits in some cases. The current study indicates that thermal evolution should be included in kink-mode oscillation models in the future to help us to better understand oscillations that are not purely Gaussian or exponential.

Understanding the Type-II spicule contribution to coronal loops

Nived Vilangot Nhalil, Armagh Observatory and Planetarium

We study the properties of coronal loop foot-point observations of Type-II spicules in the chromosphere and their signature in the EUV corona using CRisp Imaging Spectro-Polarimeter (CRISP) and co-aligned Solar Dynamic Observatory (SDO) observations with the AIA instrument. The aim of this work is to understand, whether there is a one-to-one correspondence between Type-II spicules and the hot coronal plasma signature. We find that the number density of Type-II spicules in a region close to the loop foot-point is an order of magnitude larger than that in the quiet Sun region. However, their properties such as velocity, lifetime are the same in both regions. We also find that an enhancement in the number of Rapid Blue-shifted Excursions (RBE), the disk counterpart of Type-II spicule, appears as a local brightening in the AIA 171 light curve, which confirms the role of RBEs in heating the corona. We further confirm this via simulations of coronal loop hydrodynamics performed using ARGOS. Simulations run with 1.25 × 1024 erg/pulse (corresponding to 9-10 RBEs contributing to a burst) manage to reproduce a Differential Emission Measure peak at 0.8Mk matching the observation very closely. This is a strong indication that Type-II spicules could be responsible for the heating of coronal loops. With this heating input, the simulations also reveal that the coronal loops are subject to thermal non-equilibrium with a cycle duration of 5 hours.

Magnetoseismology for the solar corona: from ~10 Gauss to coronal magnetograms

Hui Tian, Peking University

Magnetoseismology, a technique of magnetic field diagnostics based on observations of magnetohydrodynamic (MHD) waves, has been widely used to estimate the field strengths of oscillating structures in the solar corona. However, previously magnetoseismology was mostly applied to occasionally occurring oscillation events, providing an estimate of only the average field strength of an oscillating structure, which is usually about 10 Gauss. This restriction could be eliminated if we apply magnetoseismology to the pervasive propagating transverse MHD waves discovered with the Coronal Multi-channel Polarimeter (CoMP). Using several CoMP observations of the Fe XIII 1074.7 nm and 1079.8 nm spectral lines, we obtained maps of the plasma density and wave phase speed in the corona, which allow us to map both the strength and direction of the coronal magnetic field in the plane of sky. We also examined distributions of the electron density and magnetic field strength, and compared their variations with height in the quiet Sun and active regions. Such measurements could provide critical information to advance our understanding of the Sun's magnetism and the magnetic coupling of the whole solar atmosphere.

Oscillatory behaviour of the magnetic helicity flux between the flaring and non-flaring ARs

Marianna Korsos, Aberystwyth University

The magnetic helicity slowly and continuously accumulates in response to plasma flows tangential to the photosphere and magnetic flux emergence normal to it, it into the solar atmosphere. Analyzing the evolution of magnetic helicity flux at different atmospheric heights is key for identifying its role in the dynamics of ARs. The 3D magnetic field is obtained from PF extrapolations in order to derive the emergence, shearing and total magnetic helicity components at different atmospheric heights. In this presentation, we show results obtained by analysing the evolution of the three magnetic helicity components in flaring and non-flaring ARs. The evolution of the three components reveals significant periodicities of them. In the flaring ARs, we found that the emergence, shearing and total helicity fluxes have common long periods as a function height in the solar atmosphere. In the case of non-flaring ARs, we do not find such common long oscillatory periods. This case study suggests that the presence of common significant long periodicities could help for a better understanding of the physics of the lower solar atmosphere, and, this oscillatory behaviour may even serve as a valuable precursor for flares.

Evidence that resonant absorption/phase mixing are not important for energy transfer in the quiet Sun

Richard Morton, Northumbria University

The focus of many investigations on coronal wave heating has been on scrutinising the role of kink modes; examining their damping by resonant absorption and the transfer of energy to Alfvén modes. Subsequently, the Alfvén modes are then subject to phase mixing and this leads to plasma heating. More recently, a non-linear mechanism for energy transfer has also been proposed, the so called uni-turbulence. Moreover, there have been numerous observational studies on the rapidly damped standing kink modes in active regions and investigating the role of resonant absorption in the observed damping. However, their counterparts in the quiet Sun, the propagating kink waves, have received little attention. Here I will discuss the results from the measurements of kink wave damping in the quiet Sun. We find convincing evidence that the damping of the kink waves is significantly weaker than in active regions and suggests that resonant absorption/phase mixing/uni-turbulence are not important for wave-based heating of the quiescent Sun. I will also discuss the physical reason we suspect is behind this result and what it tells us about the fine scale structure of the quiescent corona.

Direct observational indications of wavelike disturbances in MBP tracks

Juan Pablo Arcila Maldonado, Universidad Nacional de Colombia

Magnetic Bright Points (MBPs) are small-scale solar atmospheric structures of highly concentrated magnetic fields that can be studied in ever more details thanks to current high precision measurements and a strong theoretical framework greatly supported by Magnetohydrodynamic (MHD) simulations and its analysis. In this study, we consider a large dataset taken from the HINODE mission from two consecutive solar atmospheric layers and analyze how MBPs evolve over time. We developed new computational techniques to track these small-scale structures and reconstruct their behavior during their lifetime. We found direct evidence for MHD wavelike disturbances within the evolution of their movement paths. We interprete these detected signatures within the MBP tracks as Kink and Sausage wave contributions which can effectively transport energy into the higher atmosphere and thus shedding light on how energy can be transferred throughout the solar atmosphere via the help of flux tubes as wave guides.

Solar cycle variations in the excitation and propagation of solar acoustic oscillations

Anne-Marie Broomhall, Rene Kiefer and Katie Kosak, University of Warwick

This talk will be split into two parts. In the first part, we will concentrate on the excitation of acoustic oscillations (p modes). Helioseismic p modes are stochastically excited in the solar interior by turbulent convection. For many years, it was believed that the rate of excitation was independent of the solar cycle phase. However, in a recent study based on GONG data, we demonstrated that instead, the rate at which energy is supplied to the modes is inversely correlated with the solar cycle, which we postulate is related to a change in the solar convection. The helioseismic oscillations on which this first study is based are below the acoustic cut-off frequency, which is the maximum frequency at which oscillations are reflected back into the solar interior, and thereby become standing waves. However, the excitation of oscillations is not limited by this frequency: Oscillations above the acoustic cut-off frequency are still excited, but rather than being reflected back into the interior at the photosphere, they propagate upwards into the atmosphere. Peaks corresponding to these oscillations can be seen in helioseismic power spectra and are referred to as pseudomodes. In the second half of this talk we will demonstrate that the frequencies of these pseudomodes, seen in GONG data, vary through the solar cycle, but, in contrast to their standing wave counterparts, the variation in pseudomode frequency is anticorrelated with solar activity. Therefore, while studying the variation of trapped acoustic waves can provide information on the magnetic field in the solar interior, these pseudomodes have the potential to provide information about the atmosphere through which they propagate.

Torsional Alfvén pulses in zero-beta flux tubes

Joseph Scalisi, University of Sheffield

We investigate the generation of mass flux due to a torsional Alfvén pulse (TAP), as observed in e.g. photospheric magnetic bright points (MBPs). A flux tube model is developed, with the waves introduced at the lower, photospheric boundary of the tube as a magnetic shear perturbation. Due to the nature of MBPs we simplify the model by using the zero-beta approximation for the plasma inside the tube. We derive that the presence of torsional Alfvén waves can result in field-aligned plasma flux formed non-linearly due to the Lorentz force generated by the perturbations. Thus the model is consistent with jet formation observed in the lower solar atmosphere. The formation of the rising mass flux may even be a viable contribution to the generation of chromospheric mass transport, playing potential roles in the form of localised lower solar atmospheric jets. The analytical results are demonstrated by an example of the type of Alfvén wave perturbation that one might expect to observe, and comparison is made with properties of spicules known from observations.

Standing MHD waves in Magnetic Annulus Geometry

Abhinav Prasad, Indian Institute of Technology, Varanasi (IIT-BHU)

Solar magneto-seismology (SMS) is a widely popular subject that involves the modelling and observation of MHD waves and oscillations present in the entire magnetized solar atmosphere. Magnetically confined configurations such as coronal loops or flux tubes are an important aspect that has been studied in great detail (Edwin and Roberts, 1983). Inhomogeneities in the structuring of magnetic field enables the flux tubes to act as wave-guides for a variety of the MHD wave modes. For example, the study of observed damping times of MHD wave modes in the solar corona led Ruderman and Roberts (2002) to suggest that there exists an inhomogeneous layer in the flux tube. Further, Carter and Erdélyi (2004); Mikhalyaev and Solov'ev (2005) studied a theoretical flux tube model of a cylindrical core surrounded by a magnetic shell wherein they investigated the propagation of ideal MHD waves and the effect of the structuring on the wave characteristics. We build on some of these theoretical models to apply the theory to standing ideal MHD waves in the magnetic annulus geometry. To model these MHD standing waves, we consider an annular cylinder of fixed length with appropriate line tying boundary conditions to derive a dispersion relation for the sausage and kink modes. We find the analytical solutions to the dispersion relation by considering the weakly homogeneous flux tube and thin annulus approximations. Further, we also consider the wide and thin flux tube cases and apply our results to solar magnetic loops from lower atmospheric oscillations (sub-photospheric tubes and chromospheric fibrils) to coronal loops. We find, in general, two purely surface and two body mode solutions in the considered structuring that we use then to determine the period ratio of the fundamental and first excited harmonic. We analyze the role of annular structuring on the period ratios of standing waves and discuss its importance in furthering our knowledge of solar magneto-seismology.

Properties of Uniturbulence in incompressible MHD

Rajab Ismayilli, KU Leuven

We are investigating MHD plasma turbulence created by unidirectional surface Alfvén waves, named "Uniturbulence". We study uniturbulence in the theoretical model with a sharp interface where one propagating surface Alfvén wave is propagating. We consider an equilibrium configuration in a Cartesian coordinate system with background magnetic field which is directed along the z axis ($\Vec{B_0}=B_0 \Vec{e}_z$) and no background flow ($\Vec{v}_0=0$). However, when there is inhomogeneity across the background, surface Alfven waves are propagating only in one direction along the field. These waves carry both Elsässer variables, $\Vec{z}^\pm = \Vec{v}\pm \Vec{B}/\sqrt{\mu\,\rho}$. We calculate explicit expressions for the wave energy and energy cascade rate. We show through a series of numerical simulations models that the non-linear self-cascade of unidirectionally propagating waves follow the derived theoretical damping time scale equation:

\begin{equation}
\tau_d = \frac{6\,\sqrt{10}}{10\,V\,k_y}\frac{\zeta+1}{\zeta-1}

\end{equation}
where V, k_y, and ζ is velocity amplitude, wavenumber, and density contrast respectively. The 3D ideal MHD simulation were run using the code MPI-AMRVAC. The existence of this type of unidirectional cascade might play a role in heating the coronal plasma and driving the solar wind.

Asymmetric waveguides in the solar atmosphere

Noemi Kinga Zsamberger, University of Sheffield

By applying the methods of solar magneto-seismology (SMS), magnetohydrodynamic (MHD) waves provide a powerful tool to diagnose the solar plasma in a range of solar atmospheric waveguides. Here, we present a family of asymmetric Cartesian waveguide models to describe MHD wave propagation and better capture the rich structuring present in a solar environment. Using our analytical results and incorporating the observational and modelling results available so far, we offer examples of an analytical and parametric investigation detailing the types of MHD waves expected to be observable in various local or global multi-layered systems of the solar atmosphere with new, high-resolution technology.

Mode conversion of two-fluid shocks in an isothermal stratified atmosphere

Ben Snow, University of Exeter

A compressional wave propagating upwards in the solar atmosphere naturally steepens due to the stratification of the atmosphere and can readily develop nonlinearities and shock. If the magnetic field is inclined, a shock can separate into fast- and slow- mode components as it passes through the point where the sound and Alfven speed are equal. This point can occur in the lower solar atmosphere, where the plasma is partially-ionised and two-fluid effects become important. Here I present results from two-fluid numerical simulations demonstrating the mode conversion and interplay between the ionised and neutral species for a shock wave propagating through an isothermal stratified atmosphere. An interesting result is that the two-fluid effects can lead to finite shock widths on the order of the pressure scale height. These large finite-widths shocks would be observable as a gradual rise in Doppler velocity over several seconds, leading to a new potential observable of two-fluid effects.

Finding the mechanism of wave energy flux damping in solar pores using numerical simulations

Julia M. Riedl, KU Leuven

Solar magnetic pores are, due to their concentrated magnetic fields, suitable guides for magnetoacoustic waves. Recent observations have shown that propagating energy flux in pores is subject to strong damping with height; however, the reason is still unclear. We investigate possible damping mechanisms numerically to explain the observations. We performed 2D numerical magnetohydrodynamic (MHD) simulations, starting from an equilibrium model of a single pore inspired by the observed properties. Energy was inserted into the bottom of the domain via different vertical drivers with a period of 30 s. Simulations were performed with both ideal MHD and non-ideal effects. While the analysis of the energy flux for ideal and non-ideal MHD simulations with a plane driver cannot reproduce the observed damping, the numerically predicted damping for a localized driver closely corresponds with the observations. The strong damping in simulations with localized driver was caused by two geometric effects, geometric spreading due to diverging field lines and lateral wave leakage. Follow-up 3D simulations featuring a more complex model also show significant lateral wave leakage.

Magnetic reconnection and the Kelvin-Helmholtz instability in the solar corona

Thomas Howson, University of St Andrews

In the solar corona, the Kelvin-Helmholtz instability (KHI) may enhance the rate of wave heating by initiating an energy cascade to small spatial scales. As the instability develops, large, localised gradients form in both the perturbed velocity and magnetic fields. In non-ideal regimes, this leads to increased viscous and Ohmic dissipation and, consequently, enhanced plasma heating. The compressive flows that form as a result of the instability force misaligned magnetic field lines together and may therefore trigger magnetic reconnection. We present the results of three-dimensional MHD simulations of driven, transverse waves in a simple geometry. In this regime, the instability is triggered by a velocity shear that forms across a resonant layer of field lines. We discuss the implications of the KHI on magnetic reconnection rates and explore the effects of field line length and non-potential equilibrium fields. In the latter case, we discuss whether the instability will enhance the background rate of magnetic energy dissipation.

On the oscillatory behaviour of magnetic helicity in flaring and non-flaring solar active regions

Szabolcs Soós, Eötvös Loránd University

In this presentation, we report the evolution of the normalized emerging, shearing and total magnetic helicity flux components for 14 flaring and 14 non-flaring active regions (ARs) of the Sun, using Spaceweather Helioseismic Magnetic Imager Active Region Patches (SHARP) vector magnetic field data. Eeach of the selected AR contains the most complex delta-type spots. Wavelet analysis was performed for each AR. Periodicity peaks were identified and were statistically analysed in the wavelet power spectrum. The main findings of this study are, (i) the Probability Density Function of periodic peaks found in flaring and non-flaring ARs is such that all of the distributions of periods appear to be arranged in bands; (ii) from the correlation of the means of Gaussians obtained from the Gaussian Mixture Model of ARs we can see that the emerging helicity flux component clearly becomes disentangled; (iii) the distributions of periodic peaks before and after the flares change in the flaring ARs. In all three cases, it can be seen that the distribution of periods varies after the flare occurrences; (iv) if in the case of a delta-spot is forming, one does not detect that the periods in the emerging helicity flux would be shortened, thereby no harmonic properties appear in it, then there is a good probability that flares would not occur; and (v) one observes that long periods (~20 hour) appear in the total and emerging helicity flux of flaring ARs, from which it can be concluded that if these periods appear one will expect flares.