BUKS 2018
WORKSHOP

Tenerife, Spain, 3-7 September

Waves and instabilities in the Solar Atmosphere

Confronting the current state-of-the-art

Abstract Booklet
Participant List

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ULL Universidad de La Laguna

Invited Review

1
Instrumentation for observing waves and instabilities, especially ALMA

Shahin Jafarzadeh

Different kinds of waves and instabilities, with a variety of properties, have been observed in the solar atmosphere. They are thought to be one of the prime candidates as agents to transport energy and momentum into the upper atmospheric layers. Identifying particular wave modes at, e.g., various spatial scales, different frequencies, or certain atmospheric layers, needs specific instrumentations and/or spectral bands. In this talk, I will review some of the recent advances of instrumentations in relation to study of the wave phenomena in the solar atmosphere. I will further argue how multi-instruments observations are essential in this regard. Particularly, I will highlight how solar observations with ALMA can improve our knowledge on, e.g., high-frequency waves. Finally, I will briefly give an outlook to some of the future instrumentations that can advance our understanding of the wave phenomena and their role in heating the upper solar atmosphere.

2
Waves, oscillations, and instabilities in the solar atmosphere: theory

M.S. Ruderman

It is impossible to review in one talk all recent progress in the theory of waves, oscillations, and instabilities in the solar atmosphere even if only to restrict it to phenomena described by MHD. Hence, I only consider four particular topics. The first topic is resonant damping of coronal loop kink oscillations as a seismological tool. Already the first observation of coronal loop kink oscillations made by TRACE in 1998 revealed that these oscillations strongly damp with the damping time of order of a few oscillation periods. At present the generally accepted mechanism of this damping is resonant absorption. It turned out that the observed damping can be used to get information about the internal structure of a loop. I will review the recent progress in using observations of damping of coronal loop kink oscillations in coronal seismology. In particular, I will discuss the new method of simultaneous determination of the density contrast and transitional layer thickness based on accurate measurement of time dependence of the oscillation amplitude.

The second topic is kink oscillations of dynamic coronal loops. One manifestation of dynamical processes in coronal loops is their cooling. I discuss the theory of kink oscillations of slowly cooling coronal loops. The coronal loop cooling also can occur in a catastrophic way that results in the formation of coronal rain. I consider the relation between the coronal rain and coronal loop kink oscillations.

The third topic is phase mixing as a mechanism for coronal heating. I briefly recall the main idea of phase mixing as a mechanism that enhances the damping of Alfvén waves. Then I review recent results on the numerical modelling of phase mixing. Finally, I describe the new model of Alfvén wave phase mixing in non-reflective and weakly reflective magnetic plasma equilibria.

The last topic is the Kelvin-Helmholtz instability induced by coronal loop kink oscillations. Since there is an invited talk completely devoted to waves and instabilities in coronal loops, I only give a very brief review of numerical studies of the Kelvin-Helmholtz instability induced by coronal loop kink oscillations. Then I present a recently developed analytical model of this instability.

3

Recent progress on observations of waves and oscillations in the solar atmosphere

Marco Stangalini

Over the last years, high resolution ground-based and space-borne observations have shed new light onto the dynamics of the solar atmosphere down to very small spatial scales. In particular, the availability of high spatial and temporal resolution multi-height observations, together with the exploitation of spectropolarimetric diagnostics, have significantly contributed to improve our understanding of the mechanisms at the base of MHD wave excitation and propagation in the solar atmosphere, and their contribution to the overall energetic budget of the upper layers of the atmosphere itself. In this talk, I will review the recent progress on observations of MHD waves and oscillations in the solar atmosphere at very high spatial and temporal resolution, with a focus on what to expect from next generation 4-meter class solar telescopes.

Invited Talk

1.- *Froment* 2.- *Jain* 3.- *Li*	4.- *Magyar* 5.- *Samanta* 6.- *Soler*	7.- *Zhang*

1
Long-period intensity pulsations in coronal loops

Clara Froment

Recent studies revealed that long-period intensity pulsations (periods from 2 to 16 hours) are very common in the solar corona and especially in coronal loops. The leading interpretation of these pulsations is that of evaporation and condensation cycles, resulting from a quasi-steady and highly-stratified heating. Such thermal cycles have long been predicted by numerical simulations, in which loops are in a state of thermal non-equilibrium. The thermal instability mechanism (runaway cooling and recombination) is thought to be the main driver of the cooling phase of the cycle, which can result in the generation of coronal rain and prominences. Understanding the characteristics of these thermal cycles is essential to understand the circulation of mass and energy in the solar corona.
I will give an overview of the latest developments, on both observations and modelling of long-period intensity pulsations in coronal loops. In particular, I will present combined observations of long-period intensity pulsations (SDO/AIA) and coronal rain with the CRISP and CHROMIS instruments at the Swedish 1-m Solar Telescope (SST) in the same coronal loop bundle. These observations allow us to probe the bulk of the cooling phases and emphasise that these pulsations and coronal rain are two aspects of the same phenomenon.

2
Helioseismology: linking the solar interior and atmosphere

Rekha Jain, Hope Thackray, Kiran Jain, Sushant Tripathy, Frank Hill

Solar p-mode inversions are derived from the Doppler velocity data measured on the surface of the Sun. Using these inversions, we investigate the sub-photospheric flows of many active regions (ARs) with and without flaring activity.

We find strong shear in the sub-photospheric flows beneath the locations of ARs with flaring activity, and the large scale flows show large variations with flare activity.
This talk will include connection between various magnetic features of the ARs and the sub-photospheric large scale flows.

3

Some seismological applications of fast collective waves in coronal structures with continuous transverse structuring

Bo Li, Shao-Xia Chen, Hui Yu, Ming-Zhe Guo, Ming Xiong

Low-frequency waves and oscillations in the magnetohydrodynamic (MHD) regime abound in the highly structured atmosphere of the Sun. Their detailed measurements, in conjunction with a continuous refinement of their theories, can help yield atmospheric parameters that prove difficult to directly measure. The magnetic field strength often tops this list of desired parameters. However, the structuring transverse to magnetic structures is also important both for understanding the fundamental properties of solar atmospheric structures and from the perspective of atmospheric heating. This talk will present some of our recent results on the theoretical understanding of both kink and sausage waves in coronal structures for which the physical parameters are transversely structured in a continuous manner. We will examine how this continuous transverse structuring influences the wave properties in general, and the periods and damping times in particular. Conversely, we will also address how the measurements of low-frequency waves and oscillations can help constrain the information on the transverse structuring. Included in this talk will be: 1) standing sausage modes in flare loops and their seismological applications for inverting the measured quasi-periodic pulsations (QPPs) in solar flare light curves; 2) impulsively generated sausage wave trains in both coronal tubes and coronal slabs together with their applications for inferring the information on sub-resolution density structuring; 3) impulsively generated kink waves in solar coronal streamers and their applications for inferring the magnetic field strength in the extended solar corona.

4

Numerical simulations of waves and instabilities in coronal loops

Norbert Magyar, Tom Van Doorsselaere

Waves are known to be ubiquitous in the solar corona. I will present the results of recent three-dimensional MHD numerical simulations on how the presence of waves in coronal structures lead to various instabilities and turbulence. The focus is on transverse (kink) MHD waves, appearing either as standing waves in magnetically closed structures such as coronal loops, or propagating waves in open magnetic field configurations such as coronal holes. Much of the work carried out and presented is concerning the nonlinear aspects of wave behaviour in the structured corona, with implications for both the coronal heating problem and coronal seismology, the two prime outcomes of coronal wave studies.

5

Waves and oscillations associated with solar jets

Tanmoy Samanta

Small-scale jets are ubiquitously observed in the solar atmosphere. These jets often display different kinds of magnetohydrodynamic waves while propagating. It is also found that these jets are sometimes responsible for producing waves in the solar atmosphere. We investigate some of these dynamic jets and associated oscillations with them using high-resolution ground and space-based observations. In the first part of the talk, the focus will be on the chromospheric and transition regions jets. I will discuss about different kinds of oscillations observed within these jets, and also how these jets and/or the process which creates jets could be responsible for generating coronal oscillations. In the second part, I will talk about oscillations of a very high-temperature jet observed at a region of the supra-arcade downflows. The implications of the observed oscillation and the mode of the wave will be discussed.

6

Energy transport and heating by torsional Alfvén waves in the partially ionized chromosphere

Roberto Soler

High-resolution observations have revealed the ubiquitous presence of Alfvén waves in the solar chromosphere. These waves are believed to play an important role in the transfer of energy from the photosphere to the overlying corona and solar wind, and in the heating of the partially ionized chromosphere. Here we theoretically investigate the energy transport and dissipation associated to torsional Alfvén waves in vertical magnetic flux tubes that expand from the photosphere to the corona. Assuming steady-state propagation, we perform 2.5D numerical computations of upward-propagating torsional waves driven at the photosphere by a broadband driver. We consider Ohm's magnetic diffusion and ion-neutral friction as dissipation mechanisms. We obtain that low frequencies are reflected in the high chromosphere and transition region, while high frequencies are dissipated in the low chromosphere. Only a small fraction of the incoming wave energy flux is able to reach coronal heights for intermediate frequencies. The dissipated wave energy causes plasma heating, which is compatible with the required heating to maintain the chromospheric temperature against radiation losses. Wave heating in the low and middle chromosphere is due to Ohmic dissipation, while ion-neutral friction dominates in the high chromosphere. The present 2.5D results show that the role of Ohmic diffusion is strongly enhanced due to the small scales generated by phase mixing because of the horizontal expansion of the magnetic field, an ingredient absent from previous 1.5D models. This effect has the important consequence of increasing the efficiency of chromospheric dissipation, and so dramatically reducing the energy flux to the corona.

7

Large amplitude prominence oscillations: observations and numerical simulations

Qingmin Zhang

In this talk, I will present our recent works on multi-wavelength observations and HD numerical simulations on large-amplitude prominence oscillations. Three types of oscillations are investigated: longitudinal, horizontal, and vertical oscillations. The triggering mechanism, restoring force, and damping mechanism are explored. Magnetic configuration and magnetic field strength of the prominences are estimated based on the observations. High-resolution and high-cadence observational data from space-borne and ground-based solar telescopes are of great importance to enrich our understanding of prominence oscillations. 3D numerical simulations with more realistic conditions being included will definitely throw light on the nature of prominence oscillations.

Contributed Talk

1.- *Adrover*	10.- *Goossens*	19.- *Khomenko*	28.- *Prokopyszyn*
2.- *Afanasev*	11.- *Grant*	20.- *Kuźma*	29.- *Pugh*
3.- *Arregui*	12.- *Guo*	21.- *Liakh*	30.- *Riedl*
4.- *Banerjee*	13.- *Gupta*	22.- *Luna*	31.- *Ruan*
5.- *Broomhall*	14.- *Heesu*	23.- *Montes-Solís*	32.- *Sangeetha*
6.- *Collados*	15.- *Hillier*	24.- *Pagano*	33.- *Sharma*
7.- *Deres*	16.- *Howson*	25.- *Pant*	34.- *Shen*
8.- *Duckenfield*	17.- *Keppens*	26.- *Pascoe*	35.- *Shestov*
9.- *Felipe*	18.- *Keys*	27.- *Popescu*	36.- *Van Damme*

1
Numerical study of a 3D prominence model: transverse and longitudinal MHD oscillatory modes

Andrés Adrover González, Jaume Terradas

The study of oscillatory motions in solar prominences allows us the estimation of physical parameters which are difficult to measure, such as the magnetic structure of the plasma. In order to describe the features of the observed oscillations, we present a new 3D numerical study of large amplitude oscillations in solar prominences.
The ideal magnetohydrodynamic (MHD) equations are solved using The Pencil Code, based on a high order finite difference method. So as to get consistent numerical solutions, we add a viscosity term in the equation of motion. We simulate a prominence embedded in a magnetic arcade surrounded by a stratified corona. Initially, the prominence reacts to the gravity force oscillating vertically due to the magnetic restoring forces. Once the structure becomes nearly relaxed, we trigger both transverse and longitudinal oscillatory modes imposing a velocity disturbance.
The results show exponentially decaying sinusoid oscillations. We find that the period of the longitudinal oscillations depends on the radius of the magnetic field lines, confirming that gravity is the main responsible for the restoring force. In addition, in case of transverse oscillations we do not find any dependence between the period and the artificial viscosity.

2
Coronal loop kink oscillations excited by different driver frequencies

A.N. Afanasev, T. Van Doorsselaere

We analyse the propagation of magnetohydrodynamic kink waves in a coronal loop, paying special attention to the problem of plasma heating. Recently, it has been shown that the plasma mixing effect due to the Kelvin-Helmholtz instability occurring at the loop boundaries contributes significantly to the temperature distribution inside a loop. Using the MPI-AMRVAC code, we perform three-dimensional numerical simulations of the propagation of magnetohydrodynamic kink waves in a gravitationally stratified magnetic flux tube. The waves are driven by transverse displacements of the tube footpoint. We consider different driver frequencies and analyse the distribution of plasma internal energy and temperature with height to understand the efficiency of that mechanism for coronal loop heating. We study the response of a coronal tube to perturbations of different frequencies, determining the tube eigenspectrum, which is of importance for analysis of a broad-band footpoint driver. We compare our results with the previous ones to reveal the effects of different driver frequencies and plasma stratification on heating of coronal loops by kink waves.

3

Inference of magnetic field strength and density from damped transverse coronal waves

I. Arregui, M. Montes-Solís, A. Asensio Ramos

A classic application of coronal seismology uses transverse oscillations of waveguides to obtain estimates of the magnetic field strength. The procedure requires assumptions on the density of the structures. It also ignores the damping of the oscillations. We computed marginal posteriors for parameters such as the waveguide density; the density contrast; the transverse inhomogeneity length-scale; and the magnetic field strength, under the assumption that the oscillations can be modelled as standing magnetohydrodynamic (MHD) kink modes damped by resonant absorption. Our results show well-defined posteriors for the magnetic field strength, even if the densities inside and outside the structure are largely unknown. Incorporating observational estimates of plasma density further constrains the inference. The amount of information one is willing to include a priori for the density and density contrast influences the obtained results, with the density being more critical than the density contrast. The decision to include or leave out the information on the damping and the damping rate itself also have an impact on the inferred magnetic field strength. The methods can be extended to prominence fine structures or chromospheric spicules and implemented to propagating waves in addition to standing oscillations.

4

Study of waves from India's solar mission Aditya L1

Dipankar Banerjee and the Aditya team

ADITYA-L1 is the first Indian mission that is dedicated to study solar atmosphere with unprecedented spatial and temporal resolution. The satellite will carry seven payloads and is expected to be launched in 2020. The main payload is the Visible Emission Line Coronagraph (VELC), an internally occulted solar coronagraph capable of simultaneous imaging, spectroscopy and spectro-polarimetry close to the solar limb, with 3 visible and 1 Infra-Red channels. Solar Ultraviolet Imaging Telescope (SUIT) will image the Photosphere and Chromosphere in near Ultraviolet (200-400 nm) and measure solar irradiance variations. In this talk I will focus on the new instrumentation, which will be available in Aditya to detect waves and characterize them with better precision and quantification. The combination of spectroscopy and imaging will be the key for the detection of waves in the low corona. A comparison with the capabilities of COMP and VELC will be highlighted. The high cadence observation with VELC with a cadence of less than a second will enable us to detect the high frequency waves. SUIT will allow the study of waves in Multi-wavelength. The potential of these new instrumentations for the study of waves will be the focus of my talk.

5

Connecting solar and stellar flares with Quasi-Periodic Pulsations

Anne-Marie Broomhall and the Solar & Stellar QPP Flares ISSI Team

Flares far more energetic than typical solar flares are routinely detected on solar-like stars raising the question of whether our star is capable of producing such enormous flares and if so what the space weather impacts would be. Regardless of the likelihood of a superflare occurring on the Sun, stellar superflares can have important consequences for habitability since many potentially habitable expolanets orbit M dwarfs, which can be far more active than our Sun. It is therefore important to understand whether the same physical processes govern solar flares and stellar superflares. Quasi-periodic pulsations (QPPs), which are quasi-periodic modulations observed in the lightcurve of a flare, have the potential to provide a solid link between the physics of solar and stellar flares and to advance our understanding of stellar magnetism in general. To do this, however, any detections must be reliable and robust. Therefore, as a team, we set up a blind *Hare-and-hound* exercise to test the limits of currently employed detection methods. In this talk we will discuss the results of this exercise to demonstrate the relative strengths and frailties of different methodologies, including those based upon periodograms, wavelets, empirical mode decompositions and Gaussian process modeling. We also discuss recent results that indicate that QPPs could be a common feature of both solar and stellar flares and highlight the synergies between the two domains.

6

Observations of the uncoupling of ionized and neutral species in solar prominences

M. Collados, *E. Khomenko*

The aim of this work is to measure possible differences in the dynamics of the ionized and neutral components of the solar plasma, as a manifestation of partial ionization effects due to an incomplete collisional coupling, causing deviations from ideal MHD. Here we report the detection of differences in ion and neutral velocities in prominences using very high temporal resolution spectral data obtained in 2012 at the German VTT (Observatorio del Teide, Tenerife). A time series of scans of a small portion of a solar prominence was obtained simultaneously with a high cadence using spectral lines of two elements with different ionization states, namely the CaII 8542 Å and the HeI 10830 Å. Displacements, widths and amplitudes of both lines were carefully compared to extract dynamical information about the plasma. Many dynamical features are detected, such as counterstreaming flows, jets and propagating waves. In all the cases we find a very strong correlation between the parameters extracted from the lines of both elements, confirming that both trace the same plasma. Nevertheless, we also find short-lived transients where this correlation is lost. These transients are associated with ion-neutral drift velocities of the order of several hundred m/s. The patches of non-zero drift velocity show coherence on time-distance diagrams. We continue and expand this initial study with another set of data, also obtained under similar conditions at the VTT in 2016, this time including He I D3 5876 Å, Halpha, and Ca II 8542 Å, measured simultaneously. The new dataset has an advantage of including two lines of neutral elements with different atomic mass, together with one line of an ionized element. The importance of such kind of simultaneous observations for detecting partial ionization effects will be emphasized.

7

Seismological diagnostic of transverse temperature distribution in coronal structures associated with sunspots

Anastasiia Deres, *Sergey Anfinogentov, Andrei Afanasev*

In this research, we investigate the possibility of applying slow MHD waves for the diagnostic of transverse temperature distribution in coronal structures associated with sunspots. Since the coronal EUV emission is optically thin, any EUV imaging instrument (like SDO/AIA) measures emission integrated along the line of sight. Therefore, interpretation of the EUV observations of coronal structures which are essentially 3D is a challenging task. To establish the influence of the transversal temperature distribution in a coronal structures on EUV observations of propagating slow MHD waves, we have to apply forward modeling.
The aim of our research is to use observation of slow MHD waves to discriminate between two models of coronal fan, corresponding to two kinds of temperature distributions: hotter interior − colder background, and colder interior − hotter background. Slow MHD waves propagating upwards in a coronal fan were modeled using Lare2D MHD code. The modeling results (temperature, density and velocity distributions) were then used as an input to FoMo forward modeling code, and synthetic SDO/AIA images at 171 Å and 193 Å were obtained. As a next step, we calculated apparent delays between oscillations seen in 171 Å and 193 Å. We found that this delay can be either positive (the wave firstly appears in 171 Å) or negative for both “cold interior” and “hot interior” models, but its dependence upon the distance from the foot-point of the fan is different. The apparent delay between oscillations observed in 171 and 193 Å channels decreases with the distance for the “cold interior” model and increases for the “hot interior”. We performed the same measurements for real observation of 3 minutes oscillations in coronal fans in active regions NOAA 11711, 11582 and 11131, and found that all of them support hot “interior model”.

8

First detection of the second harmonic of decay-less kink oscillations in a solar coronal loop

T. Duckenfield, S. A. Anfinogentov, D. J. Pascoe, and V. M. Nakariakov

Coronal loops are known to support two regimes of transverse oscillations; a large amplitude, rapidly decaying regime and an apparently decay-less, low amplitude regime. We present the first simultaneous detection of the fundamental and second harmonics of a decay-less kink oscillation in a coronal loop.

Using EUV observations taken by the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO), transverse displacements of a coronal loop are tracked at many points evenly spaced along the loop axis. To aid in the analysis of the small amplitude oscillations, a motion magnification algorithm to accentuate transverse displacements is used.

Fourier analysis of the resultant time series show the presence of two periods within the loop; $P_1 = 10.3 \pm 1.7$ minutes and $P_2 = 7.4 \pm 1.3$ minutes. The longer period component is greatest in amplitude at the apex and remained in phase throughout the loop length. The shorter period component is strongest further down from the apex on both legs and displays an anti-phase behaviour between the two loop legs. These results are interpreted as the coexistence of the fundamental and second harmonics of the standing kink mode within the loop in the decay-less oscillation regime.

We illustrate a seismological application using the period ratio $P_1/2P_2 \sim 0.79 \pm 0.16$ to constrain the density scale height as between 7-45 Mm, which is in agreement with literature. More generally, the ubiquity of decay-less oscillations in coronal loops opens up excellent perspectives for the routine diagnostics of the coronal plasma.

9

Stokes diagnostics of synthetic umbral flashes as seen by imaging spectropolarimeters

T. Felipe, H. Socas-Navarro, D. Przybylski, Heesu Yang

The use of instruments that record narrow band images at selected wavelengths is a common approach in solar observations. They allow the scanning of a spectral line by sampling the Stokes profiles with 2D images at each line position, but require a compromise between spectral resolution and temporal cadence. We evaluate the impact of the time-dependent acquisition of different wavelengths on the inversion of spectropolarimetric profiles from chromospheric lines during umbral flashes. Simulations of non-linear wave propagation in a sunspot were performed with the code MANCHA. Synthetic Stokes parameters in the Ca II 8542 Å line in NLTE were computed for an umbral flash using the code NICOLE. Artificial profiles with the same wavelength coverage and temporal cadence from reported observations were constructed and inverted. The inferred atmospheric stratifications were compared with the original models. The inferred atmospheres provide a reasonable characterization of the thermodynamic properties of the atmosphere during most of the phases of the umbral flash. Only at the early stages of the flash, when the shock wave reaches the formation height of the line, the Stokes profiles present apparent wavelength shifts and other spurious deformations. These features are misinterpreted by the inversion code, which can return unrealistic atmospheric models from a good fit of the Stokes profiles. The misguided results include flashed atmospheres with strong downflows, even though the simulation exhibits upflows during the umbral flash, and large variations in the magnetic field strength. Our analyses validate the inversion of Stokes profiles acquired by sequentially scanning certain selected wavelengths of a line profile, even in the case of rapidly-changing events such as umbral flashes. However, the inversions are unreliable during a short period at the development phase of the flash.

10

No unique solution to the seismological problem of standing MHD waves

M. Goossens, I. Arregui

The aim of this contribution is to point out that the classic seismological problem using observations and theoretical expressions for the periods and damping times of transverse standing MHD waves in coronal loops is better referred to as reduced seismological problem. Reduced emphasises the fact that only a small number of characteristic quantities of the equilibrium profiles can be determined. Reduced also implies that there is no unique solution to the full seismological problem. Even the reduced seismological problem does not allow a unique solution. Bayesian inference results support our mathematical arguments and offer insight into the relationship between the algebraic and the probabilistic inversions.

11

Alfvén wave dissipation in the solar chromosphere

S.D.T. Grant, D.B. Jess, T.V. Zaqarashvili, C. Beck, H. Socas-Navarro, M.J. Aschwanden, P.H. Keys, D. J. Christian, S.J. Houston, R.L. Hewitt

The elusive Alfvén wave has been at the centre of atmospheric heating studies for decades, due to its unique incompressible nature making it an ideal energy transporter. However, the viability of Alfvén waves as a heating mechanism in the chromosphere and beyond depends on efficient thermalisation of wave energy, which has previously been undetectable. We combine high resolution spectral imaging with advanced inversion techniques to uncover the first evidence of Alfvén wave energy conversion, in the form of non-linear shock fronts in a sunspot umbra. Observed local temperature enhancements of 5% are observed in regions where conventional umbral flash formation is inhibited, providing a unique and unprecedented insight into Alfvén wave behaviour in the solar atmosphere, and also provides avenues for future research with next generation observations.

12

Heating effects from driven transverse and Alfvén waves in coronal loops

Mingzhe Guo, Tom Van Doorsselaere, Kostas Karampelas, Bo Li

Recent numerical studies revealed that transverse motions of coronal loops can induce the Kelvin-Helmholtz instability. This process could be important in coronal heating because it leads to dissipation of energy at small scales. Meanwhile, small amplitude decayless oscillations in coronal loops have been discovered recently in the observations of SDO/AIA. We aim to model such oscillations in coronal loops and study wave heating effects, considering mixed Alfvén and kink drivers at the bottom of the flux tubes. The transverse oscillations excited in the loop can lead to the KH instability and generate small eddies. The Alfvén oscillations coming from the driver inside the loop and from the kink oscillations due to the resonant absorption around the loop boundary will have phase mixing. Both of these processes will generate small scales, which can help the dissipation of wave energy. Indeed, we can observe the increase of internal energy and temperature inside the loop. The heating is more pronounced for simulations containing the mixed driver, compared to only a kink driver. This means that the Alfvén waves are efficiently dissipated in the turbulent state of the plasma. Furthermore, we also obtained forward modelling results using the FoMo code. We obtained forward models that are very similar to the observations of decayless kink oscillations. Due to the limited resolution of instruments, neither Alfvén modes nor small scales are observable. Therefore, this numerical study shows that Alfvén modes probably can co-exist with kink modes, leading to enhanced heating.

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Exploring the damping of Alfvén waves from the broadening of spectral line profiles in the active and quiescent region corona up to 1.5 $R_\odot$

Girjesh R Gupta, Guilio Del Zanna, Helen Mason

The Alfvén wave energy flux in the corona can be explored using the density and velocity amplitude of the waves. The velocity amplitude of Alfvén waves can be obtained from the non-thermal velocity of the spectral line profiles. Previous calculations of the Alfvén wave energy flux with height in active regions and polar coronal holes provided evidence of damping of Alfvén waves with height. The results also suggested some role for thermal conduction in the damping of Alfvén waves in active regions. In this work, we present off-limb Hinode EUV imaging spectrometer (EIS) observations far above the surface, up to 1.5 $R_\odot$. The observations include an active region and a more quiescent region. We significantly improve over previous studies the estimate of non-thermal velocities by measuring the ionisation temperature using line ratios of coronal ions and also from EM-loci method. Estimates of electron densities are improved using the significant updates of the CHIANTI v.8 atomic data. More accurate measurements of the Alfvén wave energy flux and its damping will be presented up to distances of 1.5 $R_\odot$ which have not previously been explored. The results obtained from this study and possible interpretations are presented.

14

Observation of the Kelvin–Helmholtz instability in a solar prominence

Heesu Yang, Zhi Xu, Eun-Kyung Lim, Sujin Kim, Kyung-Suk Cho, Yeon-Han Kim, Jongchul Chae, Kyuhyoun Cho, Kaifan Ji

Many solar prominences end their lives in eruptions or abrupt disappearances that are associated with dynamical or thermal instabilities. Such instabilities are important because they may be responsible for energy transport and conversion. We present a clear observation of a streaming kink-mode Kelvin–Helmholtz Instability (KHI) taking place in a solar prominence using the Hα Lyot filter installed at the New Vacuum Solar Telescope, Fuxian-lake Solar Observatory in Yunnan, China. On one side of the prominence, a series of plasma blobs floated up from the chromosphere and streamed parallel to the limb. The plasma stream was accelerated to about 20–60 km s^{-1} and then undulated. We found that 2″- and 5″-size vortices formed, floated along the stream, and then broke up. After the 5″-size vortex, a plasma ejection out of the stream was detected in the Solar Dynamics Observatory/ Atmospheric Imaging Assembly images. Just before the formation of the 5″-size vortex, the stream displayed an oscillatory transverse motion with a period of 255 s with the amplitude growing at the rate of 0.001 s^{-1}. We attribute this oscillation of the stream and the subsequent formation of the vortex to the KHI triggered by velocity shear between the stream, guided by the magnetic field and the surrounding media. The plasma ejection suggests the transport of prominence material into the upper layer by the KHI in its nonlinear stage.

15

Coronal cooling as a result of the Kelvin–Helmholtz instability

Andrew Hillier, Inigo Arregui

It has been proposed that the heating of prominence threads could be the result of the Kelvin-Helmholtz instability developing on the boundary of oscillating prominence threads embedded in the solar corona. The nonlinear phase of this instability results in the mixing of the prominence material with coronal material, and also heating through compression and dissipation. In the paper we present an analytical model for the mixing at the prominence thread boundary based on conservation of mass, momentum, energy, and magnetic flux. This model details the density and temperature this layer would be expected to achieve as a result of mixing. These results show that just through mixing a transition region forms around the prominence thread at a temperature of approximately 100,000K coinciding with the disappearance of the cool prominence material. This model also shows that the kinetic energy of the turbulence is bounded by the energy of the shear flow and so any heating expected will only be efficient if the shear flow is strongly supersonic. However, for

observed speeds, the heating rates are smaller than the radiative loss rates meaning that the instability is likely to result in cooling not heating.

16
Resonant absorption in expanding magnetic flux tubes

Thomas Howson, Ineke De Moortel, Patrick Antolin

The process of resonant absorption is widely accepted to be responsible for the observed rapid damping of transversely oscillating coronal loops. In the presence of an Alfvén frequency gradient, energy is converted from large scale modes to smaller scale azimuthal Alfvén waves that exist on resonant field lines. These azimuthal motions are susceptible to dissipation through phase mixing and thus their formation is expected to enhance the rate of wave heating. However, a major criticism (Cargill et al. 2016) of wave heating models suggests that the typically assumed density structure cannot be self-consistently sustained by the dissipation of wave energy.
With this in mind, we present a model of a transversely oscillating kink wave in an expanding magnetic flux tube with a uniform density profile. The Alfvén frequency gradient required for resonant absorption is associated with a non-uniform field strength, however, the expansion of the flux tube ensures that the Alfvén speed is almost constant at the loop apex. Despite this, resonant field lines still exist within the boundary of the flux tube and so we highlight that the global properties of field lines, and not simply local conditions, determine the rate of mode conversion. In this regime, we examine the location and formation rate of small scales in the velocity and magnetic fields.

17
Phase and group diagrams for ideal two-fluid plasma waves

Rony Keppens

Starting from the well-known dispersion equation for an ideal two-fluid plasma, we present a new means to display the enormous diversity in the six wave modes accessible to a homogeneous electron-ion mixture at rest. Instead of the usual dispersion diagrams for plane waves at fixed wavevector orientation with respect to the equilibrium magnetic field, we display full phase diagrams at varying wavenumbers, which contain the well-known MHD phase diagrams or the isotropic electromagnetic or ion/electron sound wave diagrams as limiting cases. The dispersive nature of all six wave modes causes intricate variation of these phase diagrams when the wavenumber becomes comparable to the (combined electron-ion) skin depth. Even more fascinating behavior is found when the ray surface, or group diagram, is visualized, which again varies markedly from large to small wavenumber ranges. This ray surface quantifies how constructive interference of plane waves launched in all directions (resulting from a localized source) leads to an envelope that can maintain its shape, traveling at the group speed. We recover limits to Hall-MHD, and pay attention to special cases such as ion-positron mixtures, or cold plasma behavior.

18
Spectropolarimetric properties of solar magnetic bright points at high resolution

Peter Keys

Magnetic bright points are small-scale features ubiquitous across the solar surface. Found within inter-granular lanes, they are highly dynamic due to buffeting from granular cells. This dynamism, coupled with their ubiquity and strong magnetic field strengths (of the order of a kilogauss) means that they are fascinating features in the context of MHD wave phenomena and, therefore, a possible constituent to energy transfer within the various regions of the lower solar atmosphere. Here, we present results of a statistical study of their spectropolarimetric properties obtained from high resolution, ground-based instrumentation, with particular focus on the significance of these properties with respect to MHD wave phenomena in the quiet Sun.

19
Fast-to-Alfvén mode conversion in the structured media in the presence of ambipolar diffusion

Elena Khomenko, Paul Cally

Geometrical mode conversion due to stratification of the solar atmosphere plays an important role in the energy transport by waves to the chromosphere and corona, and is known to be responsible for various observed phenomena, such as e.g., acoustic halos. Thanks to this process, fast acoustic waves (p-modes) are converted into fast (magnetic) and slow longitudinal (acoustic) waves at the equipartition height where magnetic and gas pressures are equal. Higher up, where the fast magnetic mode refracts and reflects, Alfvén waves can be produced above the reflection point through the second transformation. Nevertheless, solar atmosphere is only partially ionized, and the ionization degree is extremely low in the photosphere where the mode conversion takes place. Recently, Cally & Khomenko (2018) investigated the role of the ambipolar diffusion, derived from the presence of neutrals, into the fast-to-Alfvén transformation in the approximation of cold plasma. It was found that classical ambipolar diffusion is far too weak to have any significant influence at the waves of frequencies of the order of mHz, typical for p-modes. However, large impact can be achieved if it is enhanced by the production of sufficiently small-scale structures. In that case, Cally (2017) has shown that the production of Alfvén waves is also enhanced. In the present work we extend the analytical study of Cally & Khomenko (2018) and Cally (2017) to the case of warm non-ideal plasma and structured media by performing numerical simulations of the wave propagation and conversion from the photosphere to corona. We study how the resolution of simulations influences formation of small scale structures, production of Alfvén waves and their dissipation and heating due to ambipolar diffusion mechanism.

20
Heating of the partially-ionized solar chromosphere by 2-fluid acoustic waves

Błażej Kuźma, Kris Murawski

We investigate the plasma heating resulted from 2-fluid acoustic waves propagating in the gravitationally stratified solar chromosphere. By means of high-resolution 1D simulations we study the behavior of driven high-frequency linear and non-linear waves that originate in the photosphere. We consider ions + electrons and neutrals as separate fluids which interact between their self via collision forces. Due to ion-neutral collisions high-frequency acoustic waves exhibit capability to deposit significant amount of energy in the solar chromosphere.

21
Large-amplitude oscillations in solar prominences in 2.5D models

V. Y. Liakh, M. Luna

In present work, we report the results of numerical simulations of large-amplitude oscillations in solar prominences. 2.5-dimensional magnetohydrodynamic experiments were conducted in the solar atmosphere using MHD code Mancha 3.0. The initial magnetic structure is a sheared arcade that is embedded in the gravitationally stratified atmosphere. Thermodynamics is not taken into account. Magnetic flux rope was formed as a result of reconnection of magnetic field lines due to the imposed velocity at the bottom boundary that is directed along the horizontal axis toward the magnetic inversion line. When flux rope has been formed relaxation process was activated together with prominence mass loading, so that mass relaxed with the system. Once numerical equilibrium has been reached, this system was perturbed and oscillations were studied. Different types of perturbation relative to the magnetic field were applied in order to investigate oscillations with different polarizations. The main idea of this work is to study the oscillation properties depending on the parameters of prominence such as initial shear angle, twist and mass density.

22

GONG catalog of solar filament oscillations near solar maximum

Manuel Luna, Judith Karpen, José Luís Ballester, Karin Muglach, Jaume Terradas, Therese Kucera, Holly Gilbert

We have catalogued 196 filament oscillations from the GONG Hα network data during several months near the maximum of solar cycle 24 (January - June 2014). Selected examples from the catalog are described in detail, along with our statistical analyses of all events. Oscillations were classified according to their velocity amplitude: 106 small-amplitude oscillations (SAOs), with velocities 10 km s^{-1}. Both SAOs and LAOs are common, with one event of each class every two days on the visible side of the Sun. For nearly half of the events, we identified their apparent trigger. The period distribution has a mean value of 58±15 min for both types of oscillations. The distribution of the damping time per period peaks at $\tau/P=1.75$ and 1.25 for SAOs and LAOs respectively. We confirmed that LAO damping rates depend nonlinearly on the oscillation velocity. The angle between the direction of motion and the filament spine has a distribution centered at 27° for all filament types. This angle agrees with the observed direction of filament-channel magnetic fields, indicating that most of the catalogued events are longitudinal (i.e., undergo field-aligned motions). We applied seismology to determine the average radius of curvature in the magnetic dips, $R\approx89$ Mm, and the average minimum magnetic-field strength, $B\approx16$ G. The catalog is available to the community online and is intended to be expanded to cover at least 1 solar cycle.

23

Inferring properties of oscillating prominence threads

M. Montes-Solís, I. Arregui

The formation, stability, and dynamics of solar prominences are still poorly understood. In this work, we focus on the fine threads that form prominences and their transverse oscillations. First, we consider magnetohydrodynamics models and observations to obtain information on physical properties such as the magnetic field strength, the plasma density, or the length of the threads. Then, we consider alternative models for explaining the observed damping of transverse oscillations in this type of structures and compute their relative plausibility. Bayesian techniques are used for both analyses. The results show that the physical parameters of interest can be inferred. In addition, the mechanism known as resonant absorption in the Alfvén continuum is the most plausible damping mechanism, in front of resonant absorption in the slow continuum and the Cowling's diffusion by partial ionisation of the plasma.

24

How much can the damping of the observed power spectrum of transverse waves contribute to coronal heating?

Paolo Pagano, Ineke De Moortel

Observations of coronal loops have long revealed ubiquitous, transverse velocity perturbations, that undergo strong damping as they propagate. Observational estimates show that these perturbations contain significant amounts of energy and a clear power spectrum for these transverse oscillations has been identified, composed of three distinct distributions: one for long periods, one for near 5 minutes oscillations and one for short periods. We have previously demonstrated that the damping of transverse waves can be understood in terms of coupling of the transversal modes (kink) with azimuthal modes (Alfvén) in the inhomogeneous boundaries of the loops. Moreoever this process strongly depends on the wavelength of the kink modes, where short wavelength oscillations are more efficiently damped, but carry less energy. However observed wave damping does not automatically imply dissipation and hence heating.

To investigate under which circumstances this process can contribute to coronal heating and to what extent the heating rate is sustainable, we perform 3D numerical experiments modelling the observed power spectrum of transverse oscillations including the effects of resistivity and thermal conduction.

By means of this simulation, we can address to what extent the observed power spectrum of transverse oscillations can contribute to coronal heating and how the simultaneous propagation of long and short period wavelengths affects the heat deposition distribution and more in general what is the dynamic evolution of a coronal loop upon the effect of a realistic driver.

25

First imaging observation of standing slow wave in coronal fan loops

Vaibhav Pant, Ajay Tiwari, Ding Yuan, Dipankar Banerjee

Standing slow waves are usually observed in hot and flaring coronal loops. In this study, the existence of the standing slow waves in non-flaring coronal fan loops is shown. Intensity oscillations were observed along coronal fan loops associated with the active region AR 11428. These intensity oscillations were triggered by blast waves that were generated due to X-class flares in the distant active region AR 11429. To characterize the nature of oscillations, time--distance maps along the fan loops were created. Furthermore, it was found that the intensity oscillations at two footpoints of the loops were out of phase. While moving along the fan loops, the amplitude of the oscillations first decreased and then increased. The out-of-phase nature together with the amplitude variation along the loop imply that these oscillations are very likely to be standing waves. The period of the oscillations are estimated to be ~27 min, damping time to be ~45 min and phase velocity projected in the plane of sky ~65--83 km s^{-1}. The projected phase speeds were in the range of acoustic speed of coronal plasma at about 0.6 MK which further indicates that these are slow waves.

26

Spatiotemporal analysis of coronal loops using seismology and forward modelling

D.J. Pascoe, S.A. Anfinogentov, C.R. Goddard, and V.M. Nakariakov

Combining forward modelling of the EUV profile of coronal loops with the seismological analysis of kink oscillations can be used as a powerful plasma diagnostic to strongly constrain properties such as the transverse density profile and magnetic field strength. We demonstrate this by analysing an oscillating loop for which the seismological determination of the transverse structure is inconclusive except when supplemented by additional spatial information from the intensity profile. Our method uses Bayesian analysis and Markov chain Monte Carlo sampling, extended to apply our spatial and temporal models simultaneously to the data. We compare our results with numerical simulations to quantify the uncertainties associated with the thin boundary approximation and the choice of density profile model.

27

Two-fluid modeling of waves and shocks in the solar chromosphere

Beatrice Popescu, Slava Lukin, Elena Khomenko, Angel de Vicente

Waves and shocks traveling through the chromosphere are influenced by these conditions and may acquire multi-fluid structure, similar to interstellar shocks. Here we numerically model chromospheric waves using a two-fluid approach with a newly developed numerical code. The code solves two-fluid equations of conservation of mass, momentum and energy, together with the induction equation, for the case of the purely hydrogen plasma. We present the corresponding two-fluid equations and derive expressions for the collisional terms, both elastic and inelastic ones. The implementation of semi-implicit algorithm allowed us to overcome the stability problems due to the stiff collisional terms. We satisfactory test the code against an analytical solution of the acoustic and Alfvén wave propagation in a uniform medium, not completely coupled by collisions. The results of our simulations are consistent with the analytical estimates, and with other results described in the literature. In the limit of a large collisional frequency, the waves propagate with a common speed of a single fluid. In the other limit of a vanishingly small collisional frequency, the Alfvén waves propagate with an Alfvén speed of the charged fluid only, while the perturbation in neutral fluid is very small. The acoustic waves in this limit propagate with the sound speed corresponding to either the charges or the neutrals, while the perturbation in the other specie is very small. Otherwise, when the collision frequency is similar to the wave frequency, the interaction between charges and neutrals through momentum transfer collisions cause alterations of the waves frequencies and damping of the waves amplitudes. Finally, we

considered magneto-acoustic wave propagation in a stratified medium permeated by a horizontal magnetic field. We observe that initially coupled waves in neutral and charges become decoupled at the shock fronts or because the low collision frequencies at the upper chromosphere. The decoupling height is a sensitive function of the wave frequency and amplitude, and magnetic field strength. The decoupling, similarly to the uniform medium, will cause damping of the waves, and consequently an increase of the background temperature.

28
Alfvén wave trains near a 2D null point

Alexander Prokopyszyn, Alan Hood, Ineke De Moortel

The aim of this talk is to present results from MHD wave numerical experiments in the neighbourhood of a 2D null point. We find that density gradients are generated and that phase mixing occurs despite the configuration having an initially uniform density profile. These two results are particularly interesting because they may solve one problem that many coronal wave heating models have. Namely, the problem that these models depend on density gradients but often the heating will change the temperature and density in such a way that they remove the gradients the mechanism depends on (Cargill et al, 2016). Therefore, the numerical experiment presented here could help lead to the development of a self-consistent model of wave heating by including the density structuring as part of the mechanism.

29
Linking characteristic timescales and spatial scales for quasi-periodic pulsations in solar flares

Chloe E. Pugh, Valery M. Nakariakov, Anne-Marie Broomhall

Quasi-periodic pulsations (QPPs) are quasi-periodic time variations of the intensity of radiation emitted by a flare. QPPs have the potential to be used for coronal seismology, if the mechanism causing the QPPs can be determined. Finding a link between the characteristic timescale of the QPPs and a characteristic spatial scale of the flaring region would help constrain which of the several possible mechanisms is occurring. Hence we will present recent results of an ongoing study to establish if there is a link, based on a sample of solar flares with statistically significant QPP signals and corresponding images of the flares and host active region. The spatially resolved data used are HMI line-of-sight magnetograms and AIA 1600 images. No correlations were found between the QPP periods and areas or bipole separation distances for the whole active region, determined from the HMI magnetograms, but it is still possible that a correlation between the QPP periods and spatial scales of the flaring site might exist.

30
How are p-modes converted to act as a wave driver for coronal loop simulations?

Julia M. Riedl, Tom Van Doorsselaere, Irantzu Calvo Santamaria

One of the possible mechanisms for coronal heating is the AC mechanism, where the energy for heating originates from waves driven by the turbulent motions of the photosphere and p-modes. However, it is unclear which wave driver should be considered for numerical simulations of AC heating. We build different 3D magnetohydrostatic loop systems spanning from the photosphere to the lower corona, which include both straight loops and loops with diverging field lines. These atmospheres are then simulated with the MANCHA code, where we perturb the equilibrium with a p-mode driver at the bottom of the domain. Studying the behavior of the loops after the conversion of the waves into fast and Alfvén waves allows us to establish what wave modes are predominantly excited and should be used as a driver for further numerical simulations. In particular, we will study how the conversion rate is influenced by the form of the loops and their random positioning.

31
Solar flares and Kelvin-Helmholtz instabilities

Wenzhi Ruan, Chun Xia, Rony Keppens

Hard X-ray (HXR) sources are frequently observed near the top of solar flare loops. We here revisit an scenario which stresses the importance of the Kelvin- Helmholtz instability (KHI) proposed by Fang et al. (2016). This scenario adds a novel ingredient to the standard flare model, where evaporation flows from flare-impacted chromospheric foot-points interact with each other near the loop top and produce turbulence via KHI. The turbulence can act as a trapping region and as an efficient accelerator to provide energetic electrons for HXR emission. This paper focuses on the trigger of the KHI and the resulting turbulence in this new scenario. We perform a parameter survey to investigate the necessary ingredients to obtain KHI through interaction of chromospheric evaporation flows. When turbulence is produced in the loop apex, an index of -5/3 can be found in the spectra of velocity and magnetic field fluctuations. The KHI development and the generation of turbulence are controlled by the amount of energy deposited in the chromospheric foot-points and the time scale of its energy deposition, but typical values for M class flares show the KHI development routinely. Asymmetry of energy deposition determines the location where the turbulence is produced, and the synthesized SXR light curve shows a clear periodic signal related to the sloshing motion of the vortex pattern created by the KHI.

32
Energy flux of acoustic waves in the lower solar atmosphere

Sangeetha C. R., Rajaguru S. P., Durgesh Tripathi

The problem of heating of the solar atmosphere continues to be a challenging one in astrophysics. Several studies in the recent past have shown that the small-scale inclined magnetic field elements comprising the quiet-network act as magneto-acoustic portals (e.g. Jefferies et al. 2006) through which copious amount of low-frequency acoustic waves, normally trapped below the photosphere, propagate outward extracting energy from the acoustic reservoir below. These magneto-acoustic waves are expected to shock at chromospheric heights thereby contributing to chromospheric heating. In this work, exploiting simultaneous vector magnetic field, Doppler, continuum and line-core intensity (of FeI 6173 Å) data from the photosphere (Helioseismic and Magnetic Imager HMI) and the two lower atmospheric UV emission maps in the 1700 Å and 1600 Å wavelength channels of the Atmospheric Imaging Assembly (AIA), both onboard the Solar Dynamics Observatory, we revisit the relationships between magnetic field properties (inclination and strength) and the acoustic wave propagation (phase travel time). In particular, we find that the flux of acoustic energy, in the 2 - 5 mHz frequency range, between the upper photosphere and heights corresponding to 1700 Å and 1600 Å channels is about 2.2 kW m^{-2} (which is larger than previous estimates). We also perform a detailed study of correlation between LOS, total magnetic field strengths, inclination and the chromospheric emissions in the above UV channels.

33
Complex 3-D dynamics of solar spicule structures

Rahul Sharma, Gary Verth, Robertus Erdelyi

Transverse oscillations were observed in spicules, along with periodic structural distortions, and azimuthal shear/torsion of the flux tubes in high-resolution imaging-spectroscopy studies. These perturbations were identified and reported as observed signatures of concurrent magnetohydrodynamic (MHD) kink, sausage and torsional Alfvén wave-modes. For the first time, the evolution of the resultant transverse displacement of the flux tube structure, estimated from perpendicular velocity components, is analyzed along with longitudinal, cross-sectional width, photometric and azimuthal shear/torsion variations. The pulse-like nonlinear kink wave-mode(s) shows strong coupling with these observables, with a period-doubling, -tripling aspect, supported by mutual phase relations centered around 0° and ± 180° (Sharma et al. 2018). Furthermore, the superimposition of multiple kink wave-modes, in spicular waveguide, can result in nonhelical evolution with modulation of phase speeds. The 3D ensemble of the observed dynamic components revealed complexities pertinent to the accurate identification and interpretation of e.g. linear/nonlinear, coupled/uncoupled MHD wave-modes in spicules.

34

New Observations on the Driving Mechanism and Wave Properties of EUV and QFP waves

Yuandeng Shen, *Yu Liu*

Large-scale coronal EUV waves have been studied for many years, mainly due to the unsolved problems about their physical nature and driving mechanisms. By using the high-resolution data taken by the SDO/AIA, the vast majority of previous studies proposed that large-scale EUV waves should be fast-mode MHD waves and driven by CMEs. We recently found that a part of EUV waves do not associated with CMEs. Detailed analysis results suggest that EUV waves can also be driven by the sudden expansion of coronal loops due to the impingement of fast coronal jets, or directly by recurrent coronal jets. The observational results also indicate that these EUV waves are fast-mode magnetosonic waves in the physical nature. On the other hand, we also studied several cases of quasi-periodic fast-propagating (QFP) waves that were recently discovered SDO. Our analysis results suggest that QFP waves have several possible formation mechanisms, such as non-linear energy releasing process in the magnetic reconnection that produce flares, the leakage of photospheric oscillations into the low corona, and the dispersively evolution of a board-band disturbance. In addition, filament (prominence) oscillations are also observed to be associated with EUV and QFP waves, the measured results are also used to diagnose some important coronal parameters by using the technique of coronal seismology. (the associated papers are: 2012ApJ...753...53S, 2012ApJ...752L..23S, 2012ApJ...754....7S, 2013ApJ...773L..33S, 2013SoPh..288..585S, 2014ApJ...786..151S, 2014ApJ...795..130S, 2017ApJ...851..101S, 2018ApJ...853....1S, 2018MNRAS.477L...6S, 2018arXiv180512309S, 2018arXiv180512303S. We will mainly introduce our recent studies in 2017 and 2018.)

35

Initiation of Alfvénic turbulence by Alfvén wave collisions: a numerical study

Sergei Shestov, *Yuri Voitenko*, *Andrei Zhukov*

Recent studies have revealed that the turbulence in magnetized plasmas is greatly affected by the Alfvén effect. The well-documented example is the solar-wind turbulence whose nature is essentially Alfvénic and turbulent fluctuations can be approximately described as Alfvén waves (AWs). We study using numerical MHD approach the commonly accepted presumption that the AW turbulence is generated by the collisions between counter-propagating AW. We set up a simulation box with equilibrium conditions, launch two counter-propagating Aws from the opposite boundaries, and follow their evolution observing how the wave profiles are distorted during their collision. The initial waves are linearly polarized in two orthogonal planes, their cross-field amplitude profiles vary normally to their polarization planes, and their magnetic amplitudes are about 0.1 of the mean magnetic field. Polarization and spectral properties of the perturbations generated after a single collision between such AWs were analyzed in detail. We found that the perturbations had smaller-scale across the mean magnetic field compared to the original waves, and the perturbations had different polarizations. The obtained results confirm theoretical predictions that progressively larger cross-field wavenumbers are generated by the AW collisions. However, the observed amplitudes of the perturbations (1-2% of the original AW amplitudes) are not sufficient to generate the spectral transport typical for the strong turbulence proposed by Goldreich & Sridhar (1995). Instead, the obtained spectral transport implies conditions typical for the weak turbulence where many collisions are needed to generate a single cascade step. Further simulations are underway in an attempt to figure out if a single-step cascade can be generated by two counter-propagating AWs.

36

Properties of transverse MHD waves generated by colliding flows

Hendrik-Jan Van Damme, Paolo Pagano, Patrick Antolin, Ineke De Moortel

Transverse MHD waves permeate the solar atmosphere and play a role in the dynamic and thermal evolution of the corona. However, the origin of these waves is still not completely understood. Antolin et al. (2018) analysed coordinated observations from Hinode/SOT and IRIS of a prominence/coronal rain complex at the limb of the Sun. Loop-aligned flows of cool and dense plasma were observed along a structure stemming from a prominence core high above the surface. A collision between a downward and an upward flow was observed to generate oscillatory transverse perturbations of the strands. These perturbations were interpreted as transverse sausage and kink waves based on 2D MHD simulations of colliding plasma flows. Observational signatures of the transverse perturbations were successfully reproduced. These results suggest that such in-situ collisions from counter-streaming flows could be a source of transverse MHD waves. The presence of asymmetry between the plasma flows is crucial to generate a kink mode. Using 2D MHD simulations, we present a parameter study investigating the effect of the nature of this asymmetry on the properties of the generated kink and sausage waves.

Poster

1.- *Allcock* (P)	9.- *De Moortel* (P)	17.- *Krishna* (E)	25.- *Snow* (P)
2.- *Allian* (P)	10.- *Goddard* (E)	18.- *Ledentsov* (E)	26.- *Strekalova* (P+E)
3.- *Anfinogentov* (P+E)	11.- *Håkansson* (E)	19.- *Mikhalyaev* (P)	27.- *Su* (P)
4.- *Bagashvili* (P)	12.- *Heesu* (P+E)	20.- *Montes-Solís* (P)	28.- *Thackray* (P)
5.- *Ballai* (P)	13.- *Houston* (E)	21.- *Montes-Solís* (P)	29.- *Van Damme* (P)
6.- *Carbonell* (P)	14.- *Ismayilli* (P)	22.- *Murawski* (P)	30.- *Van Doorsselaere* (P+E)
7.- *Conde* (P+E)	15.- *Karampelas* (P+E)	23.- *Popescu* (E)	31.- *Zapiór* (P+E)
8.- *Decraemer* (P+E)	16.- *Kolotkov* (P+E)	24.- *Snow* (P)	32.- *Zsámberger* (P)

P: traditional poster E: e-poster P+E: both traditional & e-poster

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1
Solar magneto-seismology with asymmetric MHD waves

Matthew Allcock, Noémi Kinga Zsámberger, Robert Erdélyi

Are solar MHD waveguides symmetric? It is convenient to assume that they are, for modelling purposes. This is why the solar physics community is familiar with the traditional notions of sausage and kink eigenmodes, which propagate along symmetric structures applicable to the solar atmosphere. In this talk, we motivate the notion of asymmetric MHD waveguides, and waves therein, and discuss their implications on mode identification. Particularly highlighting the observational ambiguity between the so-called quasi-kink waves in asymmetric waveguides and superposed symmetric kink and sausage waves. Accurate mode identification is crucial for solar magneto-seismology (SMS). We present a novel SMS technique that utilises the observed asymmetry of MHD waves to diagnose background physical parameters of the waveguide, such as the magnetic field strength, that are difficult to measure using traditional methods. The technique can be applied to prominences, elongated magnetic bright points, and sunspot light walls, amongst other solar atmospheric structures, for MHD diagnostics.

2
Oscillations in a solar coronal arcade

Farhad Allian, Rekha Jain

It is well known from observations that some solar coronal loops show large intensity variations that decay with time. Additionally, these could accompany small amplitude undamped oscillations. We investigate SDO/AIA imagery to further understand the nature of coronal loop oscillations. In particular, we carry out data analyses of oscillating loops in a coronal arcade, and study the properties of these loops.

3
Bayesian statistics and Markov Chain Monte-Carlo in the context of solar observations

S. A. Anfinogentov, D. J. Pascoe, C.R. Goddard, and V. M. Nakariakov

We present the Bayesian Statistics and Markov Chain Monte-Carlo (MCMC) technique in the context of inferring parameters of the solar atmosphere from observational data. Such an inference usually requires to solve an inversion problem and to find a model parameter set that is the most consistent with the observational data. The inversion problems are very common in the solar context. Good examples are: the estimation of the kink speed from coronal loop oscillations, measuring transverse density and temperature profiles of a coronal loop from its EUV images in different bands, and measuring the magnetic field in transition region from the observed microwave spectrum. Bayesian approach in combination with MCMC is a robust and accurate method to solve all these problems and to estimate unknown parameters and corresponding uncertainties.

Calculation of the Bayes factor is another tool provided by the Bayesian statistics. It allows for quantitative comparison of competing models (e.g. sharp vs smooth density profile, oscillations vs random noise in a flaring light curve, exponential vs Gaussian damping of kink oscillations etc).
We explain the basic principles of the Bayesian Statistics and MCMC sampling. Its practical application to parameter inference, uncertainties quantification, and model comparison is demonstrated on the example of the analysis of decaying kink oscillation profile. In this example, we do seismological inversion of the density contrast and the inhomogeneity layer width for an oscillating coronal loop. We also have confirmed the presence of additional longitudinal harmonics by calculating the Bayes factor.
Thus, MCMC based Bayesian inference is a powerful and robust method for accurate parameters inference and uncertainties estimation. Also, it allows for quantitative comparison of competing models and potentially reveals additional physical effects.

4

Evidence for precursors of the coronal hole jets in solar bright points

Salome R. Bagashvili, Bidzina M. Shergelashvili, Darejan R. Japaridze, Vasil Kukhianidze, Stefaan Poedts, Teimuraz V. Zaqarashvili, Maxim L. Khodachenko, Patrick De Causmaecker

A set of 23 observations of coronal jet events that occurred in coronal bright points has been analyzed. The focus was on the temporal evolution of the mean brightness before and during coronal jet events. In the absolute majority of the cases either single or recurrent coronal jets (CJs) were preceded by slight precursor disturbances observed in the mean intensity curves. The key conclusion is that we were able to detect quasi-periodical oscillations with characteristic periods from sub-minute up to 3–4 minute values in the bright point brightness that precedes the jets. Our basic claim is that along with the conventionally accepted scenario of bright-point evolution through new magnetic flux emergence and its reconnection with the initial structure of the bright point and the coronal hole, certain magnetohydrodynamic (MHD) oscillatory and wavelike motions can be excited and these can take an important place in the observed dynamics. These quasi-oscillatory phenomena might play the role of links between different epochs of the coronal jet ignition and evolution. They can be an indication of the MHD wave excitation processes due to the system entropy variations, density variations, or shear flows. It is very likely a sharp outflow velocity transverse gradients at the edges between the open and closed field line regions. We suppose that magnetic reconnections can be the source of MHD waves due to impulsive generation or rapid temperature variations, and shear flow driven nonmodel MHD wave evolution (self-heating and/or overreflection mechanisms).

5

Waves in partially ionised plasma in ionisation non-equilibrium

Istvan Ballai

It is widely accepted that the plasma in the lower solar atmosphere is partially ionised, with plasma made up from charged particles and neutrals. Although the exact degree of ionisation is not fully known, the ratio of ion to neutral hydrogen density covers several orders of magnitude from the photosphere to the top of the chromosphere. The plasma's ionisation state is a very important factor, as the collision between various components will significantly enhance transport processes that play an important role in the seismological diagnostics of space plasmas and serve as key mechanism in the process of plasma heating. Transport processes control the appearance and evolution of instabilities the presence of inhomogeneous flows.
Research in the dynamical evolution of physical phenomena in the solar atmosphere is based on the assumption of ionization equilibrium and the equilibrium Maxwellian distribution. However, this model is not accurate for rapidly changing phenomena, such as high frequency waves. Non-equilibrium ionization can occur during heating or cooling events, significantly affecting line intensities and subsequently the plasma diagnostics. Departures from the equilibrium Maxwellian distribution have been inferred from chromospheric and transition region line emission. In the chromosphere the ionization/recombination times scales are of the order of a few hundred seconds seconds, meaning that dynamics occurring below this scales will be affected by non-equilibrium effects.

The non-equilibrium character of the plasma will be described through the modified number-density conservation law, where separate terms will describe the creation and annihilation of ions (this will serve as a source/sink term for the equation), i.e. now the mass (or number density of particles) is not conserved. The dynamical state of the plasma is investigated within the framework of two-fluid MHD (charged particles and neutrals), with collisions between the massive particles necessary to maintain the system of particles together. Given the two-fluid approximation employed here, the spectrum of possible modes is very rich, separate modes will belong to neutrals and ions. The ionisation non-equilibrium is proven to modify the amplitude of waves and the coupling between various modes.

6

Effect of heating and cooling on the temporal behaviour of MHD waves in a partially ionized prominence plasma using different radiative loss functions

J. L. Ballester, M. Carbonell, R. Soler, J. Terradas

During heating or cooling processes in prominences, the plasma microscopic parameters are modified due to the change of temperature and ionization degree. Furthermore, if waves are excited on this non-stationary plasma, the changing physical conditions of the plasma also affect wave dynamics. We have studied how a temporal variation of temperature and microscopic plasma parameters modify the temporal behaviour of magnetohydrodynamic (MHD) waves excited in a prominence-like hydrogen plasma. Our results point out important differences in the behaviour of MHD waves when the plasma is heated or cooled, for instance, the attenuation rate is completely different in a cooling or heating process. Therefore, a correct interpretation of the observed prominence oscillations is very important in order to perform prominence seismology

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7

Waves in coronal loops observed during flaring events

Sandra Milena Conde Cuellar, Vera Jatenco-Pereira

We present a wave analysis along the coronal loops observed during C, M, and X class flares. We did this study using high spatial resolution AIA/SDO images in EUV and UV. Also, we analysed X-ray data and compared with these band passes. The temporal signals of the EUV and UV data matched with the X-ray light curve, during the period of these flares. We found high and low frequency waves in EUV and UV band passes. These waves were observed during the evolution phase of the flares. The temporal profile of the filtered signal showed damping. This was most evident in the photosphere, temperature minimum, and chromosphere regions.

8

Streamer wave events observed with STEREO/COR2

Bieke Decraemer, Tom Van Doorsselaere, Andrei Zhukov

Recently, transverse waves were observed in helmet streamers, typically after the passage of a coronal mass ejection (CME). The CME-driven shock wave moved the streamer sideways, and a decaying oscillation of the streamer was observed after the CME passage. All the previous works reported observations of streamer oscillations taken from a single vantage point (typically the SOHO spacecraft). We conduct a data survey searching for streamer wave events observed by the COR2 coronagraph onboard the STEREO spacecraft. For the first time, we can observe streamer wave events from multiple vantage points, by using the COR2 instrument on both STEREO A and B. We investigate the characteristics of streamer waves by comparing the different events and performing a statistical analysis. Common observational features give us insight on the physical nature of streamer wave events.

9
A comparison of propagating coronal disturbances (PCDs) in sunspot and plage loops

I. De Moortel, B. De Pontieu

Propagating coronal disturbances (PCDs) have long been observed as low-amplitude intensity perturbations travelling along (fan) loops in plage regions as well as in sunspot loops (loops anchored in the umbra of sunspots). Combining high resolution IRIS and SDO/AIA data, De Pontieu et al (2017) showed that the PCDs observed in plage fan loops are closely associated with spicules and the formation of new loop strands; in plage loops, PCDs appear to be a mixture of newly forming loop strands, flows and waves. Here, we compare IRIS and AIA observations of PCDs in plage loops with PCDs observed in sunspot loops and demonstrate that they are fundamentally different. We show that sunspot PCDs are associated with chromospheric and TR sunspot shock waves, travelling into the corona as slow magneto-acoustic waves.

10
The transverse density profile of coronal loops

C. R. Goddard, D.J. Pascoe, S. Anfinogentov, V.M. Nakariakov

In the era of high cadence coronal observations in the EUV band with SDO/AIA the study of coronal loops has rapidly progressed. Despite many new studies and discoveries there are still fundamental unanswered questions about the nature of coronal loops and the oscillations they exhibit. Recently, statistical studies of kink oscillations of coronal loops have been carried out. The damping envelope of many of the oscillations was found to be better described by a combination of Gaussian and exponential profiles, with the time of the switch between them allowing well-posed seismology to be performed. We have compared the seismologically returned values describing the transverse density profile to a density profile inferred from the EUV intensity, finding good agreement. This study has been extended to infer the transverse density profile of 233 coronal loops.

11
Turbulent properties, energy dissipation rate and time timescales of uniturbulence

Marcus Håkansson, Tom Van Doorsselaere

It has recently been discovered that unidirectionally propagating Alfvénic waves can cause turbulence, referred to as uniturbulence[1]. We have used data from a previous 3D simulation containing randomly placed loop strands with a transverse driver at the bottom and open boundary conditions at the top. We have performed various analyses of the results from this simulation to determine the properties of this uniturbulence. We have calculated the contents of internal, kinetic and magnetic energy at various heights. Moreover, we have computed the Poynting flux at the bottom and top of the simulation box and compared the difference with the energy dissipation rate from the structure functions. We have also estimated the timescales of phase mixing and Alfvén wave turbulence to see which process is dominating. We confirm that the uniturbulence (or generalised phase mixing) is dominant in this system compared to the classical Alfvén wave turbulence.

[1] N. Magyar, T. Van Doorsselaere, M. Goossens, Scientific Reports, 7, 2017, 14820-14820.

12

Vortex formations and its associated swirling jets in a sunspot light bridge

<u>Heesu Yang</u>, Eun-Kyung Lim, Sujin Kim, Yeon-Han Kim, Kyung-Suk Cho

Dynamical turbulence in the sun is an important mechanism to drive the energy transmission and the conversion. Due to the small dynamical scale, it has been rarely reported in low atmosphere. Here we report the successive formation of vortices with strong transverse shear flows at the boundary of a solar light bridge. The observation was done using the Goode Solar Telescope at Big Bear Solar Observatory, California. The vortices of the size less than 1 arcseconds were formed at the end of the elongated granule-like features in the photosphere. The fast-moving transverse motion features were likely associated with the flux emergence. We observed bright blobs moving upward with a speed of 4km/s right above the vortices in the H alpha images. The bright blobs occurred sequentially with a cadence of about 100 seconds. At the beginning of the vortex formations, we also observed associated swirling jets of the H alpha cool plasma reaching the chromosphere. In this presentation, we will discuss our result in the context of the KH-instability.

13

The magnetic response of the solar atmosphere to umbral flashes

<u>S.J. Houston</u>, D.B. Jess, A. Asensio Ramos, S.D.T. Grant, C. Beck, A.A. Norton, S. Krishna Prasad

Previous research has documented the ubiquitous presence of non-linear shocks that are introduced by upwardly propagating magneto-acoustic waves in sunspot umbral atmospheres. In recent years, extensive analyses have been undertaken to examine the effect of these shocks on the surrounding magnetically-dominated plasma, with previous work identifying line-of-sight modulations of the magnetic field strengths and temperature enhancements on the order of several hundred degrees Kelvin. We employ simultaneous slit-based spectro-polarimetry and spectral imaging observations of the chromospheric He I 1083nm and Ca II 854.2nm lines to examine full vector fluctuations in the umbral magnetic field caused by the steepening of magneto-acoustic waves into umbral flashes. Following the application of the HAZEL inversion routine, we find evidence to support the scenario that umbral shock events cause expansion of the embedded magnetic field lines due to the increased adiabatic pressure, hence providing increased transversal magnetic field fluctuations up to ~ 200 Gauss. Through comparisons with non-linear force-free field extrapolations, we demonstrate how the development of umbral flashes can deflect the quiescent magnetic field geometry by up to 8 degrees in both inclination and azimuthal directions.

14

MHD Kelvin-Helmholtz instability in the anisotropic solar wind plasma

<u>R. F. Ismayilli,</u> N. S. Dzhalilov, B. M. Shergelashvili, S. Poedts, M. Sh. Pirguliyev

In the MHD approximation, a shear instability of the Kelvin-Helmholtz type investigated in a temperature-anisotropic plasma. For solving this problem using a system of 16-moment MHD transport equations in a collisionless Bi-Maxwellian plasma, taking into account the heat flux along the magnetic field. Supersonic flows of two semi-infinite anisotropic and homogeneous plasma layers with different physical parameters and velocities are considered. The magnetic field directed along the interface between the plasma layers. In the general case, when the interface is a transition layer with a finite width, a differential equation for linear waves in the system derived. We derived the dispersion equation for surface waves by applying the appropriate boundary conditions for the case of a transition layer with zero width, i.e. when the interface consists of a contact discontinuity. This dispersion equation analyzed in detail in the absence of a heat flow along the discontinuity in the initial state. The results indicate that the shear flow excites the KH instability and "couples" to each other the various branches of the free-plasma oscillations. The interaction regions of modes are determined by the resonance regions, where the longitudinal phase velocities of the waves coincide. KHI occurs in resonance regions with flows with an average velocity. Calculated grows rates of

KHI as a function of the parameters, including the dependence on the degree of plasma anisotropy. It found that in most cases KHI is dominant. The results obtained applied to the solar wind plasma environment.

15
Energy distribution and structure of gravitationally stratified coronal loops

K. Karampelas, T. Van Doorsselaere

Coronal loops have been the focus of studies related to the damping of different magnetohydrodynamic (MHD) surface waves over the recent years. It has been attempted several times to connect the theory of wave damping with coronal seismology and wave heating. Different dissipation coefficients, the physical characteristics of the loops and the amount of available energy are important factors in the evolution of these phenomena. In the current work we focus on the energy dissipation from transverse waves in gravitationally stratified coronal loops. Using the PLUTO code, we perform three dimensional MHD simulations of kink waves in a straight density enhanced coronal flux tube. The temporal evolution of the energy distribution is examined for the cases of ideal, resistive and viscous MHD. The spatial evolution of the energy distribution is studied along and across the flux tube in conjunction with the development of the Transverse Wave Induced Kelvin Helmholtz, or TWIKH rolls, while drivers of different amplitude are employed. Using the FoMo code, we perform forward modelling in order to better relate our results with observations. Finally, we compare the efficiency of wave heating in our models with the findings of our previous work, for straight flux tubes in the absence of gravity.

16
Manifestation of a fast magnetoacoustic wave train in the radio emission from the solar corona

Dmitrii Y. Kolotkov, Valery M. Nakariakov, Eduard P. Kontar

Observational detection of quasi-periodic drifting fine structures in a type III radio burst associated with a solar flare SOL2015-04-16T11:22, with Low Frequency Array, is presented. Although similar modulations of the type III emission have been observed before and were associated with the plasma density fluctuations, the origin of those density fluctuations was not known. The heliocentric height of the radio emission is determined using the Newkirk model as 1.6-1.7 $R_{\odot}$. Analysis of the striae of the intensity variation in the dynamic spectrum allowed us to reveal the presence of two quasi-oscillatory components. The shorter component has the apparent wavelength of about 2 Mm, phase speed of 657 km s^{-1}, which gives us the oscillation period of about 3 s, and the relative amplitude of about 0.35%. The longer component has the wavelength of about 12 Mm, and relative amplitude of about 5.1%. The short frequency range of the detection does not allow us to estimate its phase speed. However, the properties of the shorter oscillatory component allowed us to interpret it as a fast magnetoacoustic wave guided by a plasma non-uniformity along the magnetic field outwards from the Sun. In this interpretation the shorter periodicity could result from the waveguide dispersion of the signal. The assumption that the intensity of the radio emission is proportional to the amount of plasma in the emitting volume allowed us to show that the superposition of the plasma density modulation by a fast wave and a longer wavelength oscillation of an unspecified nature could readily reproduce the fine structure of the observed dynamic spectrum of the radio emission. The observed parameters of the fast wave give the absolute value of the magnetic field in the emitting plasma of about 1.1 G which is consistent with the radial magnetic field model.

17
Thermal conductivity of sunspot fan loops

S. Krishna Prasad, J. O. Raes, T. Van Doorsselaere, D. B. Jess

Fan-like loop structures that originate in sunspots, often host propagating slow magneto-acoustic waves. Observations of these waves possess a wide variety of seismological applications and have been used to deduce important coronal parameters, such as magnetic field, temperature etc. It has also been demonstrated that their dissipation properties can be used to determine the thermal conductivity of coronal plasma. Moreover, one of the recent investigations has revealed a heavy suppression of thermal conduction in a hot flare loop. In this study, by employing similar techniques, we utilise the observations of slow magneto-acoustic waves to probe the thermal conduction properties of multiple sunspot loop structures.

18
On the origin of the consequent brightening of coronal loops in solar flare arcades

L.S. Ledentsov, B.V. Somov

With the purpose of interpreting modern satellite observations of successively increasing the brightness of individual coronal loops in solar flares, we solved the problem of the stability of small longitudinal perturbations of a homogeneous reconnecting current layer in the MHD approximation. The suppression of the plasma thermal conductivity by the magnetic field inside the current layer provides an instability. The instability increases in a radiative cooling time scale of the plasma in the linear phase. A periodic structure of hot and cold fibers arranged transversely to the direction of the electric current are formed as a result of the instability. The proposed mechanism of the thermal instability can be useful for an explanation of the consistent increase in the brightness of individual coronal loops in solar flares.

19
Nonlinear sausage mode of coronal loops

Badma Mikhalyaev, Yelagandula Naga Varun, Galina Mankaeva

The sausage mode in coronal loops is used for the interpretation of observed fast pulsations of microwave and hard X-ray emission for a few decades. Its properties are studied well in the approximation of the linear magnetohydrodynamics. Now the investigation of large-amplitude sausage waves is on the agenda. An obvious first step is to study the sausage mode in the weakly-nonlinear approximation. Previously this study has been carried out in plane geometry. We investigate weakly nonlinear sausage waves in cylindrical geometry. We derived the nonlinear Schrödinger equation describing the non-linear evolution of the wave envelope and used it to study the modulational instability.

20
Comparison of damping mechanisms for transverse waves in coronal loops

María Montes-Solís, Iñigo Arregui

Damping of transverse waves in different solar coronal structures is a commonly observed property and a source of information about coronal conditions. Although resonant damping seems to be the most accepted mechanism for damping of transverse waves, there are other possible mechanisms. We have carried out a Bayesian analysis comparing three different models which could explain the damping in coronal loops. Our results indicate that resonant absorption and wave leakage are the most probable mechanism for low ratios between damping time and wave period, while the phase mixing mechanism is the best candidate for intermediate ratios. Nonetheless, the evidence for one model against another shows a strong dependence on the data errors.

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Exponential or Gaussian damping profiles?

María Montes-Solís, Iñigo Arregui

Damping process is commonly observed in coronal structures. Standing and propagating oscillations show amplitudes decaying in a few periods. Exponential profiles have normally assumed to adjust temporal and spatial decays, but recent studies point out to Gaussian ones as more adequate to explain observations, or a mix of both. We consider the resonant absorption of propagating waves to compute, through Bayesian techniques, the plausibility of exponential or Gaussian profiles in the two principal structures of the corona, coronal loops and prominence threads. Exponential decay seems more appropriate to smaller spatial damping ratios than Gaussian ones. While in coronal loops the evidence does not support any particular profile for current observables, evidence depends on the particular values of damping length and wavelength in threads of prominences.

22

Can 2-fluid waves explain chromospheric heating and 3-min oscillations?

Kris Murawski

We present results of numerical simulations of 2-fluid waves in the solar atmosphere. These simulations are performed with the use of JOANNA code (Wojcik 2017) which adopts Godunov-type numerical methods. We show that short period 2-fluid acoustic waves, excited in the photosphere by a periodic driver, exhibit their potential to heat the chromosphere, while the waves with their periods larger than acoustic cutoff period are evanescent and they scatter their-self in the low chromosphere into shorter period waves. Granulation generates acoustic-gravity waves which in the photosphere have the period close to 5-min. In the low chromosphere, these waves scatter to 3-min oscillations. These numerical findings are in agreement of recent observational data.

23

The Rayleigh Taylor instability in the two-fluid approach

Beatrice Popescu, Slava Lukin, Elena Khomenko, Angel de Vicente

The Rayleigh Taylor instability has been frequently observed at the interface between a prominence and the solar corona. We study the growth rate of the instability in a smoothly non uniform medium in the two fluid approximation, using different configurations for the background magnetic field. We run 2D simulations with the magnetic field perpendicular to the plane defined by the gravity and the 1D perturbation, slightly rotated, and sheared. We also run 3D simulations with a 2D perturbation in the plane perpendicular to the direction of the gravity and using a sheared background magnetic field configuration. In the simulations we include non-linear effects, viscosity, thermal conduction, most of the terms in the Ohm's law and of those related to the collisions between neutrals and charges: ionization/recombination, energy and momentum transfer, and frictional heating. We compare the linear growth rate calculated from the numerical solutions to the semi-analytical solutions.

24

Ion-neutral decoupling around magnetic shocks in partially ionised plasma

Ben Snow, Andrew Hillier

The atmospheric conditions in the lower solar atmosphere result in the presence of both neutral and ionised particles. Interactions between these species can produce interesting phenomena, modifying the dynamics and resultant dissipation/heating of the system. We perform two-fluid numerical simulations analysing the behaviour of reconnection-driven shocks in the lower solar atmosphere. A parameter study has been performed investigating such shocks occurring under a wide range of atmospheric conditions, covering the lower and upper chromosphere. We find that for larger plasma-beta values (β>1) the ion and plasma species remain decoupled around shock fronts after thousands of collisional times . New features also develop around the shock front which could lead to enhanced dissipation and heating in the lower solar atmosphere.

25

Magnetic shocks and substructures from torsional wave collisions in coupled expanding flux tubes

Ben Snow, Viktor Fedun, Fred Gent, Gary Verth, Robertus Erdelyi

Vortex motions are prevalent on the solar surface, transporting energy and momentum into the upper atmosphere. The magnetic structure in the lower atmosphere consists of complex networks of flux tubes that expand and merge throughout the chromosphere and upper atmosphere. We perform numerical simulations to investigate the interactions of torsional motions in a stable pair of such flux tubes with a VAL IIIC temperature and density profile supporting the tubes. The torsional motions interact both linearly and nonlinearly. The linear interactions reorganise the magnetic field creating a series of transient magnetic substructures, i.e. the initially monolithic tube has become multistranded. A superposition of the motions also drives a shock that propagates upwards at approximately 50 km/s and heats the plasma to 60,000 K in the mid chromosphere. Therefore the interactions of torsional photospheric motions is an interesting method for energy transfer from the lower to upper solar atmosphere.

26

Interpretation of quasi-periodic oscillations of facula formations on the Sun

P. Strekalova, V. Smirnova, A. Solov'ev, Yu Nagovitsyn

Solitary small-scale magnetic structures on the solar photosphere, so-called facula formations, are investigated. Based on observations of magnetic fields and radiation in UV-lines of long-lived facula formations obtained from the SDO spacecraft, long quasi-periodic variations with periods in the range of 25-230 minutes are investigated. It is shown that during the lifetime of such formations some parameters, such as the intensity of the magnetic field, the area occupied by it on the magnetogram and on the intensity map, the intensity and other quantities can vary significantly. These changes affect the effective rigidity of the system, i.e. on the nature of the response of the system to external disturbances. The statistically significant oscillation modes for each object of interest are revealed. The obtained quasi-periodic variations of the facula formations with periods from one to several hours are interpreted as oscillations of a system with a time-varying rigidity. An analytical model describing the nature of such oscillations is proposed.

27

Period increase and amplitude distribution of kink oscillation of coronal loop

Su, W., Guo, Y., Erdelyi, R., Ning, Z.J., Ding, M.D., Cheng, X., and Tan, B.L.

Coronal loops exist ubiquitously in the solar atmosphere. These loops puzzle astronomers over half a century. Solar magneto-seismology (SMS) provides a unique way to constrain the physical parameters of coronal loops. Here, we study the evolution of oscillations of a coronal loop observed by the Atmospheric Imaging Assembly (AIA). We measure geometric and physical parameters of the loop oscillations. In particular, we find that the mean period of the oscillations increased from 1048 to 1264 s during three oscillatory cycles. We employ the differential emission measure method and apply the tools of SMS. The evolution of densities inside and outside the loop is analyzed. We found that an increase of density inside the loop and decrease of the magnetic field strength along the loop are the main reasons for the increase in the period during the oscillations. Besides, we also found that the amplitude profile of the loop is different from a profile would it be a homogeneous loop. It is proposed that the distribution of magnetic strength along the loop rather than density stratification is responsible for this deviation. The variation in period and distribution of amplitude provide, in terms of SMS, a new and unprecedented insight into coronal loop diagnostics.

28

Large scale flows beneath flaring active regions

Hope Thackray, Rekha Jain

Magnetic active regions are often host to explosive events such as solar flares. Below the photosphere, these active regions (ARs) exhibit multi-scale plasma flows. The largest of these flows are known as the meridional and zonal flows. The presence of small scale flows in and around the ARs are also believed to influence the configuration of the region, even though ARs evolve over the course of several days, moving across the Sun's surface. We investigate the large scale flows beneath many flaring ARs from different phases of the solar cycle. We use the technique of Ring Diagram Analysis (RDA) which involves temporal fourier transformation of the Doppler velocities measured from the Sun's surface. RDA stems from a branch of solar physics known as Helioseismology, where measurements of acoustic waves are used to determine the internal structure of the Sun.

29

Phase mixing of Alfvén waves and the effect of chromospheric evaporation

Hendrik-Jan Van Damme, Ineke De Moortel, Paolo Pagano

Over recent decades, observational evidence has shown that waves are ubiquitous in the solar corona. As such, wave-based heating mechanisms are attracting increased attention in the context of the coronal heating problem. In particular, phase mixing of Alfvén waves in the presence of a transverse density gradient, has been proposed as a possible mechanism to heat the corona. However, Cargill et al. (2016) highlighted that phase mixing may not be able to sustain the assumed density profile. Using MHD simulations, we consider a 2D magnetic strand in hydrostatic equilibrium to investigate the effects of chromospheric evaporation on phase mixing. Due to the non-uniform density profile, these Alfvén waves dissipate through phase mixing and increase the temperature in the boundary of the loop. We investigate how chromospheric evaporation and coronal draining influence the phase mixing process (heating and timescales), as well as the effect on the density structure.

30

Broadening of the DEM by multi-shelled and turbulent loops

Tom Van Doorsselaere, Patrick Antolin, Kostas Karampelas

In this poster, I will analyse the DEM of multi-shelled and turbulent loops. First, I will use steady-state models of multi-shelled loops to show that the width of the DEM is mainly dependent on the difference between the temperature of the interior and exterior plasma. Then, I will study 3D simulations of transversely oscillating loops (driven or impulsively excited), that evolve into transverse wave induced Kelvin-Helmholtz (TWIKH) rolls. The simulations start from delta-function DEMs, but they evolve into broad DEMs. In analogy with the steady-state models, the width of the DEMs is determined by the initial temperature structure of the oscillating loop.

31

2D multi-spectral distribution of prominence oscillations

Maciej Zapiór

We present a method of construction of 2D Dopplergams of prominences from classic slit spectrograph observations devoted to study prominence oscillations. From dataset collected during raster scanning of selected solar prominence we constructed 2D Doppler velocity maps in H-alpha, H-beta, He D3, and Ca II H spectral lines. We made it by numerical merging of individual slit observations. We studied Doppler signal in spatial and temporal domain. Data show high coherence in spatial behavior. We found oscillations with the periods 30-42 minutes, amplitudes of 0.5-6 km/s. We detected wave propagation in the plane-of-the-sky. The method may be used for any slit spectroscopy data which provides simultaneous slit-jaw images or have repetitive slit position during raster mode observations.

32

MHD waves in asymmetric waveguides: building theory and preparing high-resolution applications

Noémi Kinga Zsámberger, Matthew Allcock, Róbert Erdélyi

By developing new methods of solar magneto-seismology and applying them to the Sun, new information can be mined from solar data. This is achieved by comparing high-resolution observations with theoretical studies of magnetohydrodynamic (MHD) waves present in various magnetic geometries that can serve as models of solar atmospheric waveguides. Here, we further develop the theory of magneto-acoustic waves propagating in a homogeneous magnetic slab, by enclosing the slab waveguide in an asymmetric magnetic environment. As opposed to the classical symmetric case, our analytical and parametric investigation of the asymmetric slab system reveals that the eigenmodes possess mixed characteristics of the traditional (symmetric) sausage and kink modes. Hence, we refer to these new, mixed character modes as quasi-sausage and quasi-kink modes. We also discuss the possibility of these asymmetric modes gaining a symmetric appearance in certain systems.
The propagation of MHD waves in several solar waveguides may be described by employing approximations (such as the thin or wide slab, or the high or low plasma-beta limit) to further analytical progress. Such features include magnetic bright points, sunspot light bridges and light walls, prominences and coronal hole boundaries. Magneto-seismologic capabilities of the new model are demonstrated by a comparison with high-resolution observations, and potential future developments are explored in anticipation of the building and completion of new ground-based instruments such as DKIST or EST.

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August 30 2018