ISSI-BJ WORKSHOP

"OSCILLATORY PROCESSES IN SOLAR AND STELLAR CORONAE"

Topics

I. Sergey Anfinogentov, et al. "Novel techniques in coronal seismology data analysis"
II. Valery Nakariakov, et al. "Kink oscillations and waves in the corona"
III. Tongjiang Wang, et al. "Slow waves in coronal loops"
IV. Dipankar Banerjee, et al. "MHD waves in open coronal structures"
V. Ivan Zimovets, et al. "Quasi-periodic pulsations in solar and stellar flares"
VI. Bo Li, et al. "Sausage oscillations and waves in the corona"
VII. Tom Van Doorsselaere, et al. "Coronal heating by MHD waves"

VIII. Other

I. Sergey Anfinogentov, et al. "Novel techniques in coronal seismology data analysis"

David Pascoe

High-resolution Diagnostic Techniques for the Solar Corona

The high spatial and temporal resolution provided by the Atmospheric Imaging Assembly of the Solar Dynamics Observatory has inspired the development of advanced observational techniques to probe the solar atmosphere. For example, forward modelling of the EUV intensity of coronal structures and the seismological analysis of kink oscillations provide powerful diagnostics to constrain properties such as the plasma density and magnetic field strength. We also increasingly employ Bayesian analysis and Markov chain Monte Carlo sampling in our analysis to increase the robustness and accuracy of our modelling. These techniques are now also being applied to study quasi-periodic pulsations associated with solar and stellar flares.

Inigo Arregui

Recent results in Bayesian coronal and prominence seismology

We report on recent results from the application of Bayesian analysis techniques to seismology of coronal loops and prominence fine structures. In coronal loops, our results show that the magnetic field strength can be properly inferred, even if the densities inside and outside the structure are largely unknown. Incorporating observational estimates of plasma density further constrains the obtained posteriors. The decision to include or leave out the information on the damping and the damping timescales has a minimal impact on the obtained magnetic field strength. The methods are applied to available data sets of observed transverse loop oscillations. In prominence threads, well-constrained probability density distributions can be obtained for the magnetic field strength, the length of the thread, the density contrast, and parameters associated with damping models. In a comparison between alternative damping mechanisms, we find that resonant absorption in the Alfvén continuum is the most plausible mechanism to explain the existing observations. These results show that Bayesian analysis continues offering valuable methods to perform parameter inference and model comparison in the context of solar atmospheric seismology.

II. Valery Nakariakov, et al. "Kink oscillations and waves in the corona"

Jaume Terradas

Transverse loop oscillations from 3D MHD simulations

Over the last 20 years, coronal seismology, based on magnetohydrodynamic (MHD) waves has been used as a tool to infer different parameters in the solar corona. Estimations using this method rely on very simple theoretical models which, in most of the cases, are one or two-dimensional. Unfortunately, works based on purely three-dimensional structures are scarce. The main aim of the present work is to use realistic geometries in the theoretical models for a better understanding of coronal loop oscillations and therefore to perform improved coronal seismology. Here, coronal loops are modelled as density enhancements following curved magnetic fields in 3D. The numerical solution of the nonlinear MHD equations using these equilibrium models allows us to investigate the excitation of transverse kink MHD waves in these structures. The results of the 3D simulations are compared with the traditional linear predictions based on 1D and 2D models and it is found that the differences, for example in the period of oscillation and attenuation due to resonant damping, can be significant in some cases. In the nonlinear regime transverse oscillations inevitably generate Kelvin-Helmholtz instabilities at the tube boundary.

Peng-Fei Chen

Filament longitudinal oscillations and their decay

Longitudinal oscillations of solar filaments are an intriguing phenomenon existing ubiquitously in the solar atmosphere. It is widely believed that the restoring force is the field-aligned component of gravity. Therefore, their oscillation periods can be used to diagnose the coronal magnetic configuration. The decay of these oscillations depends on many factors. While non-ideal processes such as radiative cooling are the primary cause for the damping, we found that wave leakage also plays an important role, i.e., the filament longitudinal oscillations would excite kink motions of the magnetic field lines, whick take away the kinetic energy of the filament.

Rekha Jain

MHD waves in coronal arcades: some theoretical aspects (?)

Dong LI

Doppler shift oscillations at flaring loops observed by IRIS

In this talk, I will report the Doppler shift oscillations at flaring loops using the spectroscopic (IRIS) and imaging (SDO/AIA, SDO/HMI, Hinode/XRT) observations.
The damped oscillations were only observed in the Doppler velocity of Fe XXI 1354.08 Å at hot (11MK) flaring loops (SOL2014–10–27). They only last for several cycles, and the oscillatory period was around 3.1 minutes. The non-damping kink oscillations were simultaneously detected in the Doppler velocity, line width and peak intensity of Fe XXI 1354.08 Å at hot flaring loops (SOL2014–09–06), and they could also be observed in the HXR emission, such as Fermi 26-50 keV and GOES 1-8 Å derivative. The observed period was about 40-55 s, and the magnetic fields at flaring loops were estimated to be about 120-170 G using the MHD seismology diagnostics, which were consistent with the magnetic field modeling results using the flux rope insertion method.

Giuseppe Nistico

Determining the structure of the solar corona from cometary tails

Sungrazing comets observed with space telescopes may provide clues on the structure and dynamics of the solar corona. In the literature, only two cases of comets observed flying through the hot corona and imaged with SDO/AIA have been discussed. One of these, the comet Lovejoy, observed in December 2011, reveals unprecedented details of the interaction between the cometary tail and the surrounding coronal environment. The cometary ions trace the local magnetic fields in the form of very fine and dense open loops which appear to exhibit transverse oscillations. In this talk, we present the observations and results obtained with SDO and discuss the main consequences in the context of coronal seismology.

Hui TIAN

Spectroscopic observations of decayless kink oscillations in coronal loops and sausage oscillations in flare loops

Through UV spectroscopy, we have found two types of decay-less oscillations in the solar corona: kink oscillations in coronal loops and sausage oscillations in flare loops. Using HINODE/EIS data, we found that the upper parts of coronal loops often exhibit persistent (without significant damping) Doppler shift oscillations. These oscillations are most clearly seen in lines with Log (T/K)=6.0-6.3. The global wavelets of these oscillations usually peak sharply around a period in the range of 3-6 min. No obvious profile asymmetry is found and the variation of the line width is typically very small. The intensity variation is often less than 2%. These oscillations are more likely to be signatures of ubiquitous coronal kink/Alfvénic waves. We demonstrate that a π/2 phase shift between intensity and Doppler shift, which is often believed to be a signature of slow standing waves, could also be produced in the case of kink oscillations. We have also analyzed the IRIS data of a flare loop. Both the intensity and Doppler shift of Fe XXI 1354.08Å show clear decay-less oscillations with a period of ~25 s. Remarkably similar oscillations were also detected in the soft X-ray flux recorded by GOES. With an estimated phase speed of ~ 2420 km s−1 and a derived electron density of at least 5.4 x 10^10 cm^−3 , the observed short-period oscillation is most likely the global fast sausage mode of a hot flare loop. We find a phase shift of ~π/ 2 (1/ 4 period) between the Doppler shift oscillation and the intensity/GOES oscillations, which is consistent with a recent forward modeling study of the sausage mode.

Soheil Vasheghani Farahani

Properties of sausage and kink modes in the solar corona

The frequency, damping, damping time, phase and group speeds of fast sausage and kink waves provide clues for energy transfer by magnetohydrodynamic (MHD) in the solar atmosphere. By having in hand explicit expressions for the frequency, damping, damping time, phase and group speeds of fast sausage and kink waves in terms of the equilibrium conditions and physical parameters of cylindrical and solar slab-like plasma structures, various aspects of the wave propagation could be understood. As the sausage and kink modes leak out of the solar cylinder or slab like structure, at various cut-off frequencies, the leakage frequency of kink modes would differ with sausage modes. In the leaky regime the sausage mode phase speed is different from the kink phase speed. This could be checked by their group speeds in the external medium. Sausage waves possess higher group speeds compared to kink waves around the cut-off wave number. A comparison between the damping time of sausage and kink waves enables understanding the energy transfer range of these magnetoacoustic modes. The damping time is directly proportional with the wave number. Explicit expressions provide a qualitative comparison between the damping times in the neighbourhood of the cut-off frequency with the long wave-length limit. The presented expressions prove adequate for coronal seismology, whereas the magnetoacoustic oscillations damp and disappear, the local and neighbouring physical parameters and conditions could be estimated. The different lifetimes of MHD modes are signatures for some sort of continuous energy transport and transfer in the solar atmosphere in various scales contributing towards coronal heating in the context of coronal seismology.

Yuzong Zhang

Oscillations of Tornado observed by SDO/AIA

During 2011 September 24-26, in the southwest limb of the Sun, two barbs of a coronal filament forming a tornado structure was recorded in each Extreme Ultra Violet band by the Atmospheric Imaging Assembly instrument aboard the *Solar Dynamic Observatory* (Li et al., 2012). In this study, we focus on the oscillation and rotation properties during the formation process of the tornado. Before 09:00 UT on 24th, this was a quasi-stationary interval with two barbs of the filament connected each other and a cavity above them. The barbs began to oscillate for the first time with a period of 264 s as a small filament in the vicinity connecting and injecting material into the barbs. At about 02:00 UT on 25th, the second oscillation happened on the south barb with a period of 288 s. Two hours later, a mini-filament in north of the barbs broke out, causing the third oscillation with a period of 336 s. The barbs were twisting counterclockwise and gradually extended upward together. The center of the rotation was a long and thin tight rope-like structure, i.e., tornado vortex structure that constantly drained the surrounding material and transported it up. With the gradual disintegration of the tornado structure, the transportation process slowed down, and the counterclockwise rotation became very weak, reaching the critical point of clockwise rotation. In addition, we also found the oscillations of the coronal stream above the barbs, which shows that the activities of filament tornado are large scale beyond our previous understanding.

Gary Verth

MHD wave modes in magnetic flux tubes with elliptical cross-section

In this talk I give motivation for studying MHD waveguides of elliptical cross-section and why the standard cylinder model is not always applicable for interpreting MHD wave modes observed in photospheric and coronal waveguides. Starting with the elliptical coordinate system I will go through the derivation of the dispersion relations and explain the solutions both in terms of dispersion diagrams and visualisations of the eigenmodes. I will also go on to show the key similarities and differences to their cylindrical counterparts.

III. Tongjiang Wang, et al. "Slow waves in coronal loops"

Dmitrii Kolotkov

Effect of the thermodynamical activity of the coronal plasma on the dynamics of MHD waves

A delicate thermal balance in the coronal plasma, sustained by the simultaneous presence of both energy losses by optically thin radiation and thermal conduction and enigmatic heating mechanism, can be readily destabilised by the wave-induced perturbations of the plasma parameters. As plasma heating and cooling processes likely depend differently on the plasma density, temperature, and perhaps magnetic field, this can lead to the occurrence of the thermal misbalance. The effect of the thermal misbalance is characterized by time scales connected with the rates of change of the combined heating/cooling function with the plasma parameters, e.g. density and temperature. For coronal conditions, those misbalance time scales are found to coincide by an order of magnitude with typically observed periods of slow magnetoacoustic oscillations, i.e. to range from 1 to 30 min. This could lead to the dispersive evolution of slow waves, whereas the new dispersion is not connected with the plasma non-uniformity and is only attributed to the presence of characteristic time scales of the thermal misbalance, and to the wave damping or amplification. The latter indicates that in this regime the coronal plasma should be considered as an active medium. The new dispersion is manifested as the dependence of the effective polytropic index of the wave, and therefore of the slow wave phase and group speeds, on the wave frequency and the parameters of the initial plasma equilibrium. In the regime of the wave amplitude amplification, this could lead to the formation of dispersive evolving slow wave trains, whose dominant periods are fully determined by the misbalance time scales. In the regime of damping due to the thermal misbalance together with the standard parallel thermal conductivity, the slow wave damping rates could drop down to the observational values, depending on the properties of the heating and cooling functions considered. The comparison of the observed and theoretically predicted decay times and oscillation periods allows us to obtain additional constraints on the parameters of the coronal heating function.

Krishna Sayamanthula

The damping of propagating slow waves in coronal loops

The rapid damping of slow waves in the solar corona has been well established. A number of physical mechanisms that could cause the damping have also been identified, and a majority of the studies highlighted thermal conduction as the largest contributor. In the last few years, the damping lengths, frequency dependence and other properties of slow waves were shown to corroborate with this. However, in one of our recent studies where we investigated the temperature dependence of the slow wave damping lengths measured across several warm coronal loops, significant discrepancy has been found between the theory and observations. The results also indicate a possible suppression of thermal conduction in hot loops in agreement with a similar outcome obtained from the recent studies of standing slow waves in hot flare loops. The strengths and limitations of these results and the path forward will be discussed in this talk.

IV. Dipankar Banerjee, et al. "MHD waves in open coronal structures"

Dipankar Banerjee

Waves in the polar region

It is now believed that magnetohydrodynamics (MHD) Waves, observed via remote sensing and detected in-situ in the interplanetary space, are most likely responsible for the solar wind. The detection of these waves in the outer solar atmosphere is made possible by analyzing the effects these waves have on the plasma. The presence or signature of compressional waves may be seen in the form of variations or oscillations in radiance, due to change in plasma density, and also in the line-of-sight (LOS) velocities, due to plasma motions. On the other hand, transverse waves keep their signature in the broadening of spectral lines. I will review the status of the detection of these waves through imaging and spectroscopic methods.

Sergey Anfinogentov

Probing temperature structure of coronal fans by propagating slow MHD waves

We investigate the possibility of applying slow MHD waves for the diagnostic of transverse temperature distribution in coronal fans associated with sunspots. We investigate multi-temperature EUV observations of slow MHD waves in coronal fans to discriminate between two possible temperature distributions in coronal fans: with hot core and cold envelope and vice versa. Due to the complex line of sight (LOS) effects, the interpretation of the EUV imaging observations of coronal structures is not trivial. In particular, it is hard to determine the position of the observed disturbance on the LOS. To accurately account for the LOS effects affecting observations of propagating slow MHD waves, we use the forward modelling approach. Firstly, we use Lare2D MHD code, to model slow MHD waves propagating upwards in a coronal fan with two different temperature distributions: hot core and cold envelope, and the opposite model of a cold fan with hotter envelope. The modelling results (i.e. density and temperature) are then passed to the FoMO forward modelling code to produce synthetic SDO/AIA images at 171 Å and 193 Å. Then, we calculate apparent delays between the oscillations seen in 171 Å and 193 Å channels. We found that this delay can be either positive (the wave firstly appears in 171 Å) or negative for both temperature distribution types, but the dependence of this delay upon the distance from the foot-point is different. The apparent delay decreases with the distance for the “cold core” distribution and increases for the “hot core” model. We perform the same measurements for real observation of 3 minutes oscillations in coronal fans in three active regions and found that all of them support the “hot core” model

Wei Liu

On Flare-associated, Fast-mode Coronal Wave Trains

Quasi-periodic, Fast Propagating wave trains (QFPs) are new observational phenomena discovered by SDO/AIA in extreme ultraviolet (EUV). They are fast-mode magnetosonic waves closely related to quasi-periodic pulsations in solar flare emission ranging from radio to X-ray wavelengths. The significance of QFPs lies in their diagnostic potential, because they can provide critical clues to flare energy release and serve as new tools for coronal seismology. In this presentation, we report recent advances in observing and modeling QFPs. In particular, using differential emission measure (DEM) inversion, we found clear evidence of heating and cooling cycles that are consistent with alternating compression and rarefaction expected for magnetosonic wave pulses. We also found that different local magnetic and plasma environments can lead to two distinct types of QFPs located in different spatial domains with respect to their accompanying coronal mass ejections (CMEs). More interestingly, from a statistical survey of QFP events, we found a preferential association with eruptive flares rather than confined flares. We also identified some correlation with quasi-periodic radio bursts observed at JVLA, NAOC/Huairou, and Ondrejov observatories. We will discuss the implications of these results and the potential roles of QFPs in coronal heating, energy transport, and solar eruptions.

Leon Ofman

Modeling Flare-Associated Waves in Coronal Active Regions

Quasi-periodic fast magnetosonic propagating waves (QFPs) in active region (AR) structures have been observed with SDO/AIA in EUV and associated with flare pulsation. The waves propagates at speeds ~1000 km/s and can carry significant energy flux that may contribute to AR heating. The observed properties of the waves are useful for coronal seismology, when combined with theoretical and MHD modeling. The observed waves are often linear at low heights in the AR, but can steepen and become non-linear with height due to gravitational stratification of the density. I will present the results of recent 3D MHD models that investigate the generation, and propagation of the QFP waves. The 3D MHD models demonstrate the linear and nonlinear features of the waves, as well as the nonlinear generation of standing waves in ARs. I will discuss briefly the generation of standing slow magnetosonic waves associated with flares. I will demonstrate the applications of coronal seismology using these waves for the determination magnetic and thermal properties of realistic magnetic structures.

Vaibhav Pant

Forward modeling of transverse MHD waves in coronal holes

Several spectroscopic and imaging observations have established the ubiquity of Alfvénic waves in the solar atmosphere. Recently, an apparent discrepancy was noted in the measured Alfvénic wave energy flux in the transition region using SDO/AIA compared to those measured in the corona using Coronal Multi-channel Polarimeter (CoMP). Earlier studies have speculated that this discrepancy could be due to the unresolved wave amplitudes along the line-of-sight (LOS) in the solar atmosphere but they required the use of an additional, unknown source of Alfvénic wave energy to provide agreement with measurements of coronal non-thermal line widths. In this work, I will resolve this discrepancy by presenting 3D MHD simulations and forward modeling of transverse MHD waves in a gravitationally stratified plasma with properties similar to coronal holes in the Sun. I will present the variation of Doppler velocities and non-thermal line widths with height above the solar atmosphere. Furthermore, I will estimate the amount of underestimation of true energy in the MHD simulations due to LOS superposition of different structures in the solar corona. Finally, I will discuss the asymmetry in the emission line profile produced by the Alfvénic waves in the solar atmosphere.

Yuandeng Shen

Observational Studies of Low Frequency Coronal Waves

The talk mainly focus on two kinds of coronal waves, namely the large-scale EUV (EIT) waves and the quasi-periodic fast propagating waves. For the large scale EUV waves, we will introduce the relationships among wave signatures observed at different atmosphere layers, the observational evidences of the wave nature and the driving mechanisms of EUV waves, as well as the role of EUV waves in triggering large amplitude filament oscillations. For quasi-periodic fast propagating waves, we mainly introduce the exciting mechanism and their relationship between the flare quasi-periodic pulsations.

Liping Yang

Excitation of MHD waves by plasmoid ejection in solar corona reconnection

In this study, we numerically investigate the excitation of MHD waves in the interchange reconnection scenario in the solar corona. The modeling results show that as a result of tearing instability, the magnetic reconnection occurs, accompanying the creation of plasmoids. The created plasmoids are quickly shot, and strongly collide with the magnetic field in the outflow regions, which consecutively triggers the perturbations of velocity component Vx , Vy , and Vz . The perturbations of Vy satisfy the polarity relations of slow-mode wave, and their propagating speed approaches the sonic speed in the model, while the perturbations of Vz satisfy the polarity relations of Alfven wave, and their propagating speed is about the Alfven speed, thus verifying that they are slow-mode waves and Alfven waves, respectively. These simulation results indicate that not only fast-mode wave but also slow-mode wave and Alfven wave can be simultaneously excited by plasmoid ejections and releases.

V. Ivan Zimovets, et al. "Quasi-periodic pulsations in solar and stellar flares"

Xingyao Chen

Quasi-periodic Pulsations before and during a Solar Flare in AR 12242

QPPs are frequently observed in both thermal and nonthermal energy releases. Three different QPPs with different time scales during different flaring phase were presented in an M8.7 flare on Dec 17, 2014: UV QPPs with 4-min near the center of the active region, EUV QPPs with 4-min along the circular ribbon, and radio QPPs with 2 mins around the flaring source region. The flare was with circular ribbons over multiple-scale loop structures as revealed by AIA/SDO. There were groups of small-scale low-lying arcades or loops, intermediate dome-like structure, and the large-scale loops as shown in EUV images involved in this flare process. The spectral structure of the quasi-periodic pulsations overlaid on a type IV solar radio continuum and related radio images in the frequency range 1.2–2.0GHz were recorded by MUSER-I. From the multi-wavelength observations of this flare and the related magnetic field structures, their possible mechanisms were also discussed in this work.

Il-Hyun Cho

Comparison of Damped Oscillations in Solar and Stellar X-Ray flares

The similarity and difference of the quasi-periodic pulsations (QPPs) observed in the decay phase of solar and stellar flares at X-rays were explored (Cho et al. 2016). For this, we identified 42 solar flares with pronounced QPPs, observed with the RHESSI, and 36 stellar flares with QPPs, observed with the XMM-Newton. The empirical mode decomposition (EMD) method and least-square fits by a damped sine function were applied to obtain the periods (P) and damping times (τ) of the QPPs. We found that (1) the periods of the solar and stellar QPPs are 0.90 ± 0.56 and 16.21 ± 15.86 minutes; (2) the damping times of solar and stellar QPPs are 1.53 ± 1.10 and 27.21 ± 28.73 minutes; (3) the ratios of the damping times to the periods (τ /P) observed in the solar and stellar QPPs are 1.74 ± 0.77 and 1.69 ± 0.56, which are statistically the same each other; (4) the scalings of the QPP damping time with the period are well described by the power law in both solar and stellar cases. The power indices of the solar and stellar QPPs are 0.96 ± 0.10 and 0.98 ± 0.05, respectively. This scaling is consistent with the scalings found for standing slow magnetoacoustic and kink modes in solar coronal loops. Thus, we propose that the underlying mechanism responsible for the stellar QPPs is the natural magnetohydrodynamic oscillation in the flaring or adjacent coronal loops, as in the case of solar flares.

Guannan GAO

Intermittent Sequence of Decimetric type U solar radio bursts and EUV Jet Phenomena on 2011 February 9

We investigated decimetric solar radio bursts observed by the Hiraiso Radio Spectrograph (HiRAS) and Yunnan Observatories Spectrometer (YNOS) on February 9, 2011. In addition to the radio data, we also studied the data in other wavelengths. The bursts were associated with an M1.9 flare and EUV jets took place from active region AR 11153. The radio data displayed reverse-drifting (RS) type III bursts, intermittent sequence of type U bursts, drifting pulsation structures (DPSs), type N burst and radio storm from 01:26:24 to 01:36 UT. Especially, after the DPS, which is the radio signature of the plasmoids, the generation rate of type U bursts suddenly increases 5 times than before. To some extent, the generation ratio of type U bursts may represent magnetic reconnection rate. Our observations are consistent with previous results, magnetic reconnection rate was suddenly increasing 5 times than before, when the plasmoids appeared, obtained by the numerical experiments. In addition, before these radio bursts, the Solar Dynamics Observatory/Atmospheric Imaging Assembly (AIA) channels (94, 131 and 171 \AA) reveal propagating EUV disturbances between the footprints of the arcade loops from 01:15 to 01:26 UT. During these radio bursts, AIA hot channels (94 \AA, 131 \AA) show the emergence of new magnetic loop, it is possible to reconnect with the original magnetic lines, and high temperatures and dense flows, chromospheric evaporation were found together. After the generation of type U bursts, AIA 171, 304 \AA and Solar Terrestrial Relations Observatory EUVI-A 304 \AA show the three jets have the same onset time, but they have different kinematics characteristic.

Andrew Inglis

The AFINO approach to finding oscillations in solar and stellar flares: latest results and updates

The Automated Flare Inference of Oscillations (AFINO) code provides a novel, statistically conservative approach to identifying oscillatory signals in solar and stellar flare data. This tool enables large sample studies of flares and other coronal phenomena. AFINO has also been used in wider contexts to search for discrete ULF waves in the magnetosphere. We present the AFINO methodology and discuss the main results obtained so far using this approach, as well as its advantages and disadvantages compared to other methods. Finally, we discuss expected updates and improvements to the analysis code.

Elena Kupriyanova

Problems and challenges of studying the non-stationary properties of QPPs

Alexey Kuznetsov

Modulation of radio emission mechanisms by MHD waves

Radio emission of solar and stellar flares often contains quasi-periodic structures, with respect to both time and frequency. These structures are believed to reflect MHD waves and oscillations in the coronae. The MHD waves can affect the radio emission in different ways - from triggering quasi-periodic particle acceleration to direct modulation of the radio-wave generation process by changing the emission source parameters. In this talk, I briefly review how the MHD waves can modulate the incoherent (gyrosynchrotron) and coherent (maser and plasma) emission mechanisms, what are the expected observable patterns, and how the observations can be connected with the MHD wave parameters.

James McLaughlin

Modelling Quasi-Periodic Pulsations in Solar and Stellar Flares

Solar flare emission is detected in all EM bands and variations in flux density of solar energetic particles. Often the EM radiation generated in solar and stellar flares shows a pronounced oscillatory pattern, with characteristic periods ranging from a fraction of a second to several minutes. These oscillations are referred to as quasi-periodic pulsations (QPPs), to emphasize that they often contain apparent amplitude and period modulation. We review the current understanding of quasi-periodic pulsations in solar and stellar flares. In particular, we focus on the possible physical mechanisms, with an emphasis on the underlying physics that generates the resultant range of periodicities. These physical mechanisms include MHD oscillations, self-oscillatory mechanisms, oscillatory reconnection/reconnection reversal, wave-driven reconnection, two loop coalescence, MHD flow over-stability, the equivalent LCR-contour mechanism, and thermal-dynamical cycles. We also provide a histogram of all QPP events published in the literature at this time. The occurrence of QPPs puts additional constraints on the interpretation and understanding of the fundamental processes operating in flares, e.g. magnetic energy liberation and particle acceleration. Therefore, a full understanding of QPPs is essential in order to work towards an integrated model of solar and stellar flares.

Fabio Reale

X-ray flare periodic pulsations from sloshing wavefronts along star-disk magnetic tubes in the Orion star-forming region

Long-lasting X-ray flares are often observed in pre-main sequence stars. Large-amplitude (~20%), long-period (~3 hr) pulsations are detected in the light curve of day-long flares observed by the Chandra mission from pre-main sequence stars in the Orion cluster. Detailed hydrodynamic modeling of two flares observed on V772Ori and OWOri shows that these pulsations may track plasma pressure wavefronts moving back and forth along a single long magnetic tube, triggered by a sufficiently short (~1 hr) heat pulse. These magnetic tubes are 20 solar radii long, enough to connect the star with the surrounding disk. The same model matches well pulsations in the light curve of hot solar coronal loops observed with SDO/AIA.

Baolin Tan

Radio QPPs Occurred in Precursor Phase of Solar Flares

Solar flares are the most violent explosions in the solar system, which may release huge amount of energy, accelerate great number of energetic non-thermal particles, and eject hot plasma flows, produce strong disturbance in the interplanetary space and greatly impact on the terrestrial environment. It is one of the main key problems of solar physics to understand the origin of solar flares and to predict their occurrence and evolutions. As we know that the main features of solar flares include the variations of magnetic field in the source regions, radiation of energetic non-thermal particles and the motions of hot plasmas, and these features have much more sensitive response in decimeter and centimeter wavelength of radio observations than in other wavelengths. This talk plans to report the primary results of radio precursors of solar flares by analyzing the observation data of the Chinese Solar Broadband Radio Spectrometer (SBRS/Huairou) and Nobeyama Radio Spectrometers (NoRP). We find that QPPs with periods of several minutes at radio emissions occurred in the precursor phase of many flare events. Such results may help us to understand the triggering mechanism of solar flares.

Yihua Yan, et al.

MUSER Observations Associated with Coronal Oscillations in Flare Events

We present the solar radio bursts observed by the Mingantu Spectral Radioheliograph (MUSER) in China with 25 ms cadence and 25 MHz spectral resolution at 0.4-2.0 GHz and other multi-wavelengths imaging observations of an M8.7 flare/CME event on 2014 December 17. The solar radio spectral observations show quasi-periodic pulsations overlaid on a type IV radio continuum, which present oscillations of the non-thermal emission at a period of about 2 minutes during the flaring impulsive phase. The imaging observations show that the radio bursts cover above a region with positive magnetic field in the middle of this active region. Additionally, the modeling extrapolation shows that there are three magnetic topological structures with different scales of lengths, which coincide with the EUV imaging observations. We also find that the circular ribbon is brightening, expanding and oscillating at a period of about 3 minutes during the preflare phase.

The above associated spatial locations suggest that the EUV oscillations during preflare phase are possibly related to the radio oscillations during the flaring impulsive phase. Those results also suggest that the null-point reconnection may happen before the flare onset and the preflare oscillations may play an important role in triggering the following solar flare. The MUSER observations for other events are also shown.

Ding Yuan

Spatial extent of a QPP during a M-class flare

Quasi-periodic pulsations (QPP) are usually found in the light curves of solar and stellar flares, they carry the features of time characteristics and plasma emission of the flaring core, and could be used to diagnose the coronas of the Sun and remote stars. In this study, A QPP with a period of about four minutes was detected in the AIA 131 \AA{} bandpass and the NoRH 17 GHz channel. The Distribution of Fourier power shows that this QPP originated from a compact source, and it overlapped with the X-ray source above the loop top. Within this region, the plasma emission intensities were highly correlated. The source region is further segmented into stripes that oscillated with distinctive phases. These characteristics could not be explained by either repetitive magnetic reconnection or modulations by waves. So far, we not clear what nature could explain these features.

Qingmin Zhang

Chromospheric Condensation and Quasi-periodic Pulsations in a Circular-ribbon Flare

In this paper, we report our multiwavelength observations of the C3.1 circular-ribbon flare SOL2015-10-16T10:20 in active region (AR) 12434. The flare consisted of a circular flare ribbon (CFR), an inner flare ribbon (IFR) inside, and a pair of short parallel flare ribbons (PFRs). The PFRs located to the north of IFR were most striking in the \textit{Interface Region Imaging Spectrograph} (\textit{IRIS}) 1400 {\AA} and 2796 {\AA} images. For the first time, we observed the circular-ribbon flare in the Ca {\sc ii} H line of the Solar Optical Telescope (SOT) aboard \textit{Hinode}, which has similar shape as observed in the Atmospheric Imaging Assembly (AIA) 1600 {\AA} aboard the Solar Dynamic Observatory (\textit{SDO}). Photospheric line-of-sight magnetograms from the Helioseismic and Magnetic Imager (HMI) aboard \textit{SDO} show that the flare was associated with positive polarities and a negative polarity inside. The IFR and CFR were cospatial with the negative polarity and positive polarities, implying the existence of a magnetic null point (\emph{\textbf{B}}$=$\textbf{0}) and the dome-like spine-fan topology. During the impulsive phase of the flare, ``two-step'' raster observations of \textit{IRIS} with a cadence of 6 s and an exposure time of 2 s show plasma downflow at the CFR in the Si {\sc iv} λ1402.77 line ($\log T\approx4.8$), suggesting chromospheric condensation. The downflow speeds first increased rapidly from a few km s^{-1} to the peak values of 45$-$52 km s^{-1}, before decreasing gradually to the initial levels. The decay timescales of condensation were 3$-$4 minutes, indicating ongoing magnetic econnection. Interestingly, the downflow speeds are positively correlated with logarithm of the Si {\sc iv} line intensity and time derivative of the \textit{GOES} soft X-ray (SXR) flux in 1$-$8 {\AA}. The radio dynamic spectra are characterized by a type \Rmnum{3} radio burst associated with the flare, which implies that the chromospheric condensation was most probably driven by nonthermal electrons. Using an analytical expression and the peak Doppler velocity, we derived the lower limit of energy flux of the precipitating electrons, i.e., 0.65$\times$10^{10} erg cm^{-2} s^{-1}. The Si {\sc iv} line intensity and SXR derivative show quasi-periodic pulsations with periods of 32$-$42 s, which are likely caused by intermittent null-point magnetic reconnections modulated by the fast wave propagating along the fan surface loops at a phase speed of 950$-$1250 km s^{-1}. Periodic accelerations and precipitations of the electrons result in periodic heating observed in the Si {\sc iv} line and SXR.

Xiaozhou Zhao (Talk: V. Review: V)

Forward modeling of a simulated flux rope ejection

We conduct forward modeling analysis based on MHD simulation of magnetic flux rope (MFR) eruption. In the forward modeling analysis, the coronal and chromospheric plasmas are assumed to be in local thermal equilibrium, then the relative populations of the various atomic levels are obtained by solving the Saha equation based on the temperature and density obtained from the MHD simulation. The EUV emission coefficients are proportional to the electron number density squared. The cool and dense plasma is considered to be optically thick, where the absorption is due to photoionization of neutral hydrogen and neutral and once-ionized helium. Due to the lack of non-thermal particles in MHD simulation, only thermal X-ray emission is calculated based on the optically thin thermal bremsstrahlung model. The current sheet (CS) evolution during MFR eruption can be divided into four stages. The first stage shows the CS to form and gradually lengthen with a low reconnection rate. Resistive instabilities that disrupt the CS mark the beginning of the second stage, and the magnetic reconnection rate increases drastically. Magnetic islands disappear in the third stage accompanied by a low reconnection rate, and reappear in the fourth stage together with a high reconnection rate. Synthetic images and light curves of the seven Solar Dynamics Observatory (SDO)/AIA channels, i.e., 94Å, 131Å, 171Å, 193Å, 211Å, 304Å, and 335Å, and the 3 – 25 keV thermal X-ray are obtained with forward modeling analysis. The loop-top source and the coronal sources of the soft X-ray are reproduced in forward modeling. The light curves of the seven SDO/AIA channels start to rise once resistive instabilities develop. The light curve of the 3 – 25 keV thermal X-ray starts to go up when the reconnection rate reaches one of its peaks. Quasi-periodic pulsations (QPPs) appear twice in the SDO/AIA 171Å, 211Å, and 304Å channels, corresponding to the period of chaotic (re)appearance and CS-guided displacements of the magnetic islands. QPPs appear once in the SDO/AIA 94Å and 335Å channels after the disruption of the CS by resistive instabilities and in the 193Å channel when the chaotic motion of the magnetic islands reappears.

VI. Bo Li, et al. "Sausage oscillations and waves in the corona"

Zhong Liu

Accurate measurement of sausage oscillations

High resolution observation with ground-based large solar telescope is an important method for measuring of sausage oscillation. However, the accuracy of ground-based observation is always limited by the turbulence of the earth's atmosphere, even if the telescope has a very good adaptive optical system. In order to measure the sausage oscillation with high accuracy, some special methods are developing at FSO. In fact, as one of the science cases of 8m Chinese Giant Solar Telescope, accurate measurement of sausage oscillations will be tested firstly on the 1m New Vacuum Solar Telescope.

Mijie Shi

Synthetic Ultraviolet Emissions from Coronal Loops experiencing Fast Sausage Modes

Forward modeling the emission properties in ultraviolet (UV) passband is important for confidently identifying magnetohydrodynamic waves using the modern imaging and spectroscopy instruments in the structured solar corona. In our work, we examine the UV emissions from sausage modes supported by a straight magnetic tube. We incorporate non-equilibrium ionization into the computation of the emissivity, taking the Fe IX 171 Å and Fe XII 193 Å lines as examples. We find that non-equilibrium ionization effects can considerably change the line intensity while have little effects on the Doppler width or Doppler velocity. Using the spatial and spectral resolutions of IRIS, we then forward model the Fe XXI 1354 Å line of sausage modes in flare loops and examine their observational signatures. Our results are largely consistent with a recent IRIS observations of sausage modes in flare loops. We also synthesize the EUV emissions of leaky sausage modes with the data from MHD simulations. Our results show that the damping time from intensity variations can largely reflect the damping time of sausage modes if the loop temperature is not drastically different from the emission line's formation temperature. These results are helpful to identify sausage modes in solar corona using the modern instruments.

VII. Tom Van Doorsselaere, et al. "Coronal heating by MHD waves"

Patrick Antolin

Kink waves as stepping-stone agents for magnetic reconnection heating in coronal loops

Abstract: -

Mingzhe Guo

Wave heating in simulated multistranded coronal loops

It has been found that the Kelvin-Helmholtz instability (KHI) induced by both transverse and torsional oscillations in coronal loops can reinforce the effects of wave heating. In this study, we model a coronal loop as a system of individual strands, and we study wave heating effects by considering a combined transverse and torsional driver at the loop footpoint. We deposit the same energy into the multistranded loop and an equivalent monolithic loop, and then observe a faster increase in the internal energy and temperature in the multistranded model. Therefore, the multistranded model is more efficient in starting the heating process. Moreover, higher temperature is observed near the footpoint in the multistranded loop and near the apex in the monolithic loop. The apparent heating location in the multistranded loop agrees with the previous predictions and observations. Given the differences in the results from our multi-stranded loop and monolithic loop simulations, and given that coronal loops are suggested to be multistranded on both theoretical and observational grounds, our results suggest that the multistrandedness of coronal loops needs to be incorporated in future wave-based heating mechanisms.

Ineke De Moortel

Aspects of MHD wave heating in the complex solar atmosphere

In a series of numerical experiments, we investigate the possible role of MHD waves in the energy and mass cycle in the complex solar corona. Using 3D MHD simulations of transverse, Alfvenic waves, we look at the role of chromospheric evaporation, the complexity of the magnetic field and the power spectrum of the wave driver. We focus on the efficiency of the wave-based heating in our models, in particular whether heating provided by the waves can balance coronal losses and whether proposed wave heating mechanisms are in fact self-consistent.

Norbert Magyar

A novel prospect on coronal heating by MHD turbulence

The existence of a multi-million-degree solar corona still lacks a satisfying explanation. As dissipative coefficients are extremely small, correspondingly small scales need to be created to dissipate the available kinetic/magnetic energy to heat. One mechanism to provide this is thought to be turbulence, consisting in a nonlinear cascade of energy down to dissipation scales. In this talk, I will start by briefly reviewing what we know about turbulence in the solar corona. I will focus on the current understanding about the origin of turbulence in MHD. Then, I will expand on the recently realized phenomenon of self-cascading MHD waves in an inhomogeneous plasma, which is a novel way to generate turbulence. I will show both a theoretical understanding and numerical verifications of this new theory.

Abhishek Srivastava

Novel Heating Candidates for the Localized Solar Corona: High-frequency Torsional AlfvénWaves, Psuedo-shocks, and Forced Reconnection

The advent of high-resolution observatories both in ground and space reveal variety of localized plasma processes in the lower solar atmosphere diverse spatio-temporal scales, which may potentially contribute to the transfer of energy in the overlying Sun's inner corona causing its heating. In the present talk, I discuss some recent advances on understanding such heating candeidates of the localized solar chromosphere and corona thereby their implications in possible heating of Sun's localized atmosphere. We will discuss the role of high frequency torsional Alfven waves, pseudo-shocks, and forced reconnection, in which the first two were enforced from the lower solar atmosphere while the last one is found as an *in situ* mechanism worked in the localized solar corona to energize it locally. Such new developments may have potential to give novel insight on understanding the energization of Sun's corona in greater details in the light of upcoming ultra-high-resolution observatories (e.g., 4m-n DKIST, 2m-NLST, Parker's Probe etc).

VIII. Other

Jiangtao Su

High resolution observations of Sunspot Oscillation with BBSO/GST

I will report several interesting observations about the running waves in sunspots by the Goode Solar Telescope at the Big Bear Solar Observatory. The first one is the propagating modes of umbral running waves, second is two umbral oscillations driving one penumbral running wave (PRW) and last is excitating of umbral oscillations closely associated with PRWs.