# 'Symphony of Waves and Plasma (SWAP): Insights into Solar Atmospheric Coupling in the High-Resolution Era (SWAP)' Abstracts

## Talks

### Analysis of solar surface oscillations and energy transports with bispectral electronic thermostatistics

**Authors**

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**Abstract**

The ubiquitous five-minute solar \textit{p}-mode oscillations, excited at the photosphere, play a fundamental role in helioseismology and in transporting energy toward the upper solar atmosphere. Since the photospheric plasma contains significant nonthermal electron populations, their influence on oscillation dynamics and stability must be systematically examined. We adopt a generalized double-spectral electronic thermostatistical framework based on the $(r, q)$-distribution to analyse the dispersion, growth behaviour, and mechanical energy transport properties of longitudinal helioseismic modes. A local linear perturbative treatment of an inhomogeneous, viscous, turbulent, and nonthermal plasma yields a cubic eigenmode (dispersion) equation describing coupled global modes. The effects of the nonthermality indices $(r, q)$, electron temperature, and ion dynamic viscosity on dispersion and stability are investigated numerically. Results show that the spectral indices $r$ and $q$ exert mode-accelerating influences, counterbalancing thermal and viscous damping. The coupling between thermal and suprathermal electrons significantly modifies oscillation characteristics and growth rates. High-frequency \textit{p}-modes are found to carry acoustic energy fluxes exceeding $10^6$ W m$^{-2}$ near the lower photosphere, sufficient to energize the chromosphere and quiet corona, potentially enhancing spicule and coronal loop dynamics. In contrast, low-frequency \textit{g}-modes show negligible contribution to coronal heating. A hybrid power-law decay formalism models the attenuation of \textit{p}-mode energy flux with height. The results are consistent with Doppler observations from SDO/HMI. These findings provide new insights into the nonthermal modulation of helioseismic oscillations and their role in solar atmospheric energy transport.

## Decayless kink oscillations in solar coronal loops (Invited)


### Authors

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### Abstract

Coronal waves have been intensively studied due to their potential role in coronal heating and their application in plasma diagnostics. One particularly promising candidate is the recently discovered low-amplitude decayless kink oscillations, which are ubiquitous in the solar corona. Their undamped nature suggests the presence of a continuous energy input counteracts dissipation, although the exact physical mechanism remains debated. This talk will explore the properties and driving mechanisms of decayless kink oscillations based on high-resolution observations with SDO/AIA and SolO/EUI, and recent insights from numerical simulations. Their possible implications for coronal heating will be discussed as well.

## TBC (Invited)

### Authors

TBC (1)

(1) TBC

### Abstract

TBC

# Compression, Impact and Hot Rebound Flows from Coronal Rain Downflows


## Authors

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## Abstract

Studying coronal rain formation through thermal non-equilibrium (TNE) and thermal instability (TI) provides insights into coronal heating mechanisms. We analysed a quiescent coronal rain event using space-based observations from the High-Resolution Imager in Extreme Ultraviolet (\hrieuv) of Solar Orbiter (SolO), the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO), and the Slit-Jaw Imager (SJI) from the Interface Region Imaging Spectrograph (IRIS) from November 1st, 2023. During the coronal rain shower, the coronal loop exhibits substantial EUV variability and structural changes. Rain clumps fell at $72-87$~km~s$^{-1}$ with cool EUV absorbing core sizes of $\approx$600~km and densities of $\approx6\times10^{11}$~cm$^{-3}$ preceded by strong compressions. These mostly isothermal compressions suggest energy transfer into the rain, decelerating it and possibly reducing cooling rates -- consistent with accretion braking timescales. The shower carried microflare-level energy ($4.64\times10^{26}$~erg), with clumps producing impacts that reach the lower transition region and are visible across all EUV channels and in SJI~1400~\AA. The impacts generated hot rebound flows ($10^{6.2}-10^{6.3}~$K, $85-87$ km~s$^{-1}$) that refilled and reheated the loop but carried less than $15\%$ of the clumps' kinetic energy. We detected steady footpoint heating signatures consistent with the TNE-TI scenario, with an estimated amplitude of $10^{-2\pm0.3}~$ erg~cm$^{-3}$ ~s$^{-1}$ and heating scale heights of $2-10$~Mm, matching active region values. Coronal rain may thus serve as both a template for accretion braking and a proxy for integrated heating driving TNE-TI cycles.

## What drives propagating slow waves in sunspot-anchored coronal fans?


### Authors

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### Abstract

Propagating slow magnetoacoustic waves are ubiquitous in the solar corona and are widely used as diagnostics of plasma conditions and magnetic structure, magnetohydrodynamic seismology. However, the mechanism responsible for setting their dominant periods remains debated, with two competing interpretations: the acoustic cut-off frequency and resonant cavity behaviour in the lower atmosphere. Resolving this ambiguity is key to understanding how wave energy is generated and transported through the Sun's coupled atmospheric layers.

In this study, we investigate the origin of slow-wave periodicities in sunspot-anchored coronal fans using SDO/AIA observations. Time–distance analysis of multiple fan structures reveals the presence of several distinct periodicities within the three-minute band. These coronal signatures are closely associated with enhanced chromospheric oscillations at the same periods, indicating a direct coupling between the lower atmosphere and the corona. To interpret these observations, we employ a 1D model of wave propagation in a stratified atmosphere including an acoustic cavity. The model demonstrates a transition in the dominant mechanism controlling the observed periods, from cut-off behaviour to resonant response, as the atmospheric conditions vary. This provides a natural explanation for the coexistence of both regimes in observations.

## A universal scaling between damping time and period of decay phase quasi-periodic pulsations

### Authors

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### Abstract

Quasi-periodic pulsations (QPPs) are a ubiquitous signature of impulsive energy release in solar and stellar flares. Recent high spatial and temporal resolution extreme ultraviolet (EUV) observations from Solar Orbiter have revealed that QPPs are also present in much smaller-scale solar coronal events known as EUV brightenings. The identification of these EUV brightenings as manifestations of the same underlying physical mechanism responsible for flares is a crucial hypothesis in coronal heating theories by nanoflares. Whether QPPs observed across such disparate spatial and energetic scales share a similar physical origin remains an open question. Here, we focus on single-period, exponentially damped QPPs detected during the decay phase of the light curve. We show that such QPPs observed in EUV brightenings exhibit damping behaviour comparable to that observed in solar and stellar flares. The relationship between damping time and oscillation period follows a consistent power-law scaling for EUV brightenings and EUV solar flares, and is compatible with previously reported X-ray QPPs in both solar and stellar flares. The universality of this scaling over a wide range of energies and scales supports the interpretation that decay phase damped QPPs are governed by a broadly common underlying physical mechanism.

## A self-consistent solar coronal heating model by Alfvenic waves


### Authors

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### Abstract

Alfvenic waves are prevalent throughout the solar atmosphere and are believed to play an essential role in coronal heating, classified as alternating current (AC) heating in contrast to direct current (DC) heating associated with quasi-static magnetic field line braiding. The relative importance of AC versus DC heating depends on the details of the photospheric driver and on the configuration of the magnetic field. Moreover, the dominant wave dissipation mechanism among several proposed ones remains unclear, as it depends on plasma compressibility and density inhomogeneity. We address these issues by performing three-dimensional radiative magnetohydrodynamic (MHD) simulations of a coronal loop spanning from the upper convection zone to the corona, which self-consistently capture many relevant physical processes. We find that the corona is predominantly heated by AC heating, with Alfven wave turbulence providing the primary contribution, accounting for at least 80% of the entire coronal heating. Our results strongly support the use of Alfven wave turbulence--based models employed in space weather and stellar activity research, such as the Alfven Wave Solar Model (AWSoM) and the Magnetohydrodynamic Algorithm outside a Sphere (MAS).

# Forward modelling MUSE observables of MHD waves in a coronal loop


## Authors

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## Abstract

High-resolution, high-cadence EUV observations of the solar atmosphere have established the ubiquitous presence of waves and initiated an ongoing discourse around the energization of the hot solar corona through wave energy dissipation. However, constraining the processes that drive coronal heating from observations presents a formidable challenge due to the intricate nature of the solar atmosphere. In this study, we present our most recent simulation results of driving transverse waves by random-motion footpoint drivers within a loop model, with emphasis on forward modeling of observables for the forthcoming Multi-slit Solar Explorer (MUSE) mission. Using the PLUTO code, an initial three-dimensional coronal loop model anchored in chromospheric plasma is constructed, employing a cross-field background heating profile that sustains the loop against losses from radiative cooling and thermal conduction. Switching to a uniform heating profile that only sustains the background atmosphere, we compare the effects of high- and low-amplitude random velocity drivers with a broadband spectrum on the dynamics and energy evolution of the flux tube. As the boundary-driven transverse waves propagate along the loop, the radial density profile and velocity shears at the loop boundary result in enhanced energy dissipation and wave heating due to resonant absorption, phase mixing, and the Kelvin-Helmholtz instability. Targeting the MUSE Spectrograph (SG), we will present observables of wave-induced heating, signatures of the manifested instabilities in the loop cross-section and of magnetic field-parallel flows, through mass exchange between the corona and chromosphere, within our model.

## Five-minute periodicities in the population of solar coronal brightenings


### Authors

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### Abstract

The population of small-scale brightenings observed across broad regions of the quiet Sun (QS) corona shows coherent strong periodicities of 5 minutes and amplitudes of 20 to 30% of the mean. The periodicity is in the total number of detected brightenings, their creation rate, and their mean lifetime. The Atmospheric Imaging Assembly/Solar Dynamics Observatory Extreme Ultraviolet data spanning two hours shows that the periodicity is significant across broad areas of the QS. The periodicities are strong in the hotter 171A (300s period) and 193A channels (300s and 340s periodicity respectively) but absent from the upper chromospheric 304A channel, although periodicities are present in the 304A channel in other datasets. The density of brightenings is highest above the photospheric network with an increasingly pronounced network concentration in the hotter channels. An extended study of 11 QS datasets spanning several years shows that these periodic modulations are common, with most periodicities found in the 4 to 6 minute range. The time profile of area and brightness for most of the brightenings show a non-impulsive gradual onset inconsistent with local reconnection, and the brightenings are more likely to appear first in the 171A channel, then in the hotter 193A channel. This suggests that the most plausible formation mechanism is wave or shock dissipation at, or near, the transition region likely connected to spicule activity. This heating is modulated by photospheric p-modes and drives the production of transient brightenings in the QS upper chromosphere, transition region, and low corona.

# Influence of Structured Field- Aligned Flows on the Damping of Kink Oscillations in Fine- Scale Cool Coronal Loops


## Authors

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## Abstract

Magnetohydrodynamic kink oscillations observed in solar coronal loops provide a powerful diagnostic of coronal plasma and magnetic field properties through coronal seismology. Understanding the physical mechanisms that govern the damping of these oscillations is therefore essential for the accurate interpretation of high-resolution observations. We investigate the role of structured field-aligned plasma flows in controlling the damping of impulsively excited standing kink oscillations in fine-scale, cool coronal loop strands under isobaric conditions. Using two-dimensional ideal magnetohydrodynamic simulations, we model realistic flow configurations motivated by observations, including bounded, unbounded, and external flow profiles, as well as longitudinally inhomogeneous flows. The loop strands are modeled with strong density contrasts ($d = 5$ and 20), representative of cool coronal structures frequently observed by Hinode/SOT and SDO/AIA. We find that field-aligned flows have only a weak influence on the oscillation period, but substantially modify the damping behavior. In particular, unbounded flows extending both inside and outside the strand produce the strongest damping, reducing the damping time by up to ∼25% compared to cases with flows confined within the strand. This enhanced attenuation is attributed to stronger wave–flow coupling and increased scattering and leakage of wave energy into the surrounding corona. Longitudinally varying flow profiles further amplify the damping, with higher-density strands exhibiting a more rapid convergence toward the uniform-flow regime. For sufficiently strong internal flows, we additionally observe the excitation of slow sausage-mode harmonics and the formation of weak slow shocks, indicating the emergence of mixed-mode wave dynamics in flow-dominated environments. Our results demonstrate that realistic, spatially extended plasma flows are a key factor governing kink-mode damping and should be incorporated into forward modeling and coronal seismology diagnostics.

## Posters

### Hinode/EIS observation of the Alfv\'enic fluctuations in the quiet Sun


#### Authors

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#### Abstract

Alfvénic fluctuations in the corona are regularly observed in EUV imaging and infrared spectroscopic data.

We report here on the Doppler velocity fluctuations within the data from \textit{Extreme Ultra-Violet Imaging Spectrometer} (EIS) on board Hinode. The capabilities of EIS provide an opportunity to detect fluctuations in the solar atmosphere, and confirm the previous results from ground-based spectroscopic data using EIS's EUV spectra and in seeing-free conditions. We analysed Doppler velocity time series for a particular date of observation, 27 Sep 2007, above the limb. The Fourier transform of the observed signals show the Doppler velocity has a broad spectrum distributed as a power law with a power enhancement around 3-4 mHz. This result is consistent with previous observational results obtained with \textit{Coronal Multi-Channel Polarimeter} data, hence we interpret the Doppler velocity fluctuations as Alfvénic in nature. We performed non-linear regression on the power spectra to determine the index of the power law and to parameterise the properties of the enhancement. We find good agreement between the estimated values and those from previous studies.

Furthermore, correlation analysis shows that the observed oscillations are spatially coherent perpendicular to the magnetic field on length scale $L_{\perp}\sim8$ Mm, providing an estimate on the energy injection scale of a bundle of coherently oscillating loops.

## Alfven Waves in Partially Ionised Solar Steady-State Plasmas


### Authors

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### Abstract

Alfven waves play a fundamental role in the dynamics and energy transport of the solar atmosphere, particularly in regions where the plasma is partially ionised. In such environments, collisions between ions and neutrals, together with background flows, can significantly influence wave behaviour.
In this work, we investigate the propagation and damping of Alfven waves in partially ionised solar plasmas in the presence of steady, field-aligned flows of both ions and neutrals. A two-fluid model is adopted, treating ions and neutrals as coupled but distinct fluids. The analysis combines analytical investigation of the dispersion relation with numerical solutions to explore the role of key physical parameters.
Our results show that steady flows introduce important modifications, including Doppler shifts, changes in propagation direction, and flow-dependent damping rates. We also identify an additional mode associated with neutral motion and collisional coupling. Furthermore, we determine conditions under which flow-driven mode conversion can occur between different wave branches.
These results provide insight into the interaction between wave dynamics, collisional effects, and background flows in partially ionised regions of the solar atmosphere, with implications for chromospheric wave propagation and energy transport.