Coronal Loop Workshop

Abstract booklet

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Connecting coronal loops and kink wave heating: an analytical and numerical study

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Oral

The coronal heating problem remains a central challenge in solar physics, requiring a detailed understanding of wave-based heating mechanisms. Among them, kink waves and their turbulent dissipation likely play a significant role in heating of the solar corona. Their contribution to the heating has recently been formalised and included in the physics-based Uniturbulence and Alfvén Wave Solar Model (UAWSoM) coronal model, with promising results. In this work, we investigate how kink wave heating may affect coronal loops. A detailed study of coronal loop characteristics and behaviour is conducted under the assumption that a loop is sustained primarily by kink wave heating. We employ both the analytical and numerical methods originating from the well-known RTV scaling laws, as well as perform 1D MHD simulations of coronal loops using the UAWSoM model. This approach allows us to extensively compare the results obtained by each method. As a result, we provide scaling laws and robust numerical estimates of the wave energy density needed to sustain a loop against radiative losses, report on the effects on statics and dynamics of coronal loops, and compare with previous results. In addition, this study serves as an important step in validating the UAWSoM model, assisting its further development.

Evolution of Impulsive Heating in Active Region NOAA 12712

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It is well-known that the heating frequency, the timescale on which energy release occurs on a given coronal strand, is variable over any given active region and that this spatial distribution of heating frequencies may vary from one active region to the next. However, a systematic study of this inter- and intra-active-region variation has not been carried out and furthermore it is not well-known how these variations are connected to the magnetic properties of the active region.In this talk, we examine the evolution of the spatial distribution of heating frequencies in active region NOAA 12712 over the course of over two days from 2018-05-30 to 2018-06-01. To carry out this investigation, we use spectroscopic data from Hinode/EIS and imaging data from SDO/AIA to construct spatially-resolved maps of the differential emission measure (DEM) and time lag, respectively, for multiple raster observations of NOAA 12712. Additionally, we carry out a series of field-aligned hydrodynamic simulations constrained by field extrapolations derived from HMI observations of this active region. By making systematic, quantitive comparisons between the aforementioned observations and forward-modeled observables from our simulations, we are able to map out the most-likely heating frequency across each raster observation. Furthermore, we explore the correlation between this distribution of heating frequencies and the changing magnetic properties of NOAA 12712 as quantified by the Space weather HMI Active Region Patch (SHARP) parameters.

Sunspot torsional oscillation

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Poster

Sunspots have been observed to rotate around their central axes. This rotation can change direction to form torsional oscillations. The rotation twist the magnetic field around them into spiral structures. Rotating sunspots are also the source of flare production, indicating a change in magnetic field connectivity of the chromosphere and corona. A driver of the torsional oscillation is magnetoconvection under the photosphere in which the magnetic flux bundle is rooted. The nonlinear compressible magnetohydrodynamic equations are solved numerically in two dimensions, investigating axisymmetric solutions in the upper convection zone. A parameter study is presented of the plasma conditions, the strength of the magnetic field and the convection cells around it, in order to use the frequencies and amplitudes of the torsional oscillations as a diagnostic probe of the plasma conditions and magnetic field strengths in and around sunspots.

Application of a multi-species NLTE modeling framework to impulsive coronal heating and the partition of energy among particle species

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Oral

Conventional approaches to constructing numerical models of the solar atmosphere assume a fully equilibrated plasma, wherein all particle species are in collisional thermal equilibrium amongst themselves and each other. This yields single fluid formulations of the governing evolution equations, such as ideal MHD, or, at best, a treatment that accommodates different electron and ionized hydrogen and helium temperatures. In reality, a comparison between the timescales of observed coronal activity and inter-species equilibration timescales demonstrates that the former can be significantly shorter than the latter. There are important consequences for the emission spectra used to deduce the partition of energy among physical processes (e.g. thermal, turbulence, waves) and among different particle species. For example, observed emission lines can be substantially broader than forward-modeling predictions made by setting the ion temperature equal to the electron temperature (or to the formation temperature of the ion in equilibrium). This can lead to misleading interpretations associated with the need for excess broadening mechanisms (e.g. turbulence) and/or the preferential energization of particular particle species. We will present a new multi-species modeling framework to accommodate the NLTE coupling between arbitrary species and some recent results from its application to impulsive coronal heating that concern thermal vs. non-thermal processes and energy partition among species.

Heating and heat conduction in the transition region of coronal loops

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Oral

Traditional 1D coronal loop models suggest that the transition region is predominantly heated by heat conduction from the corona, at least if constant volumetric heating is assumed. However, when the spatial heating profile is modified, local energy deposition in the transition region can become more important. Recent advances in 3D MHD models enable the investigation of the relative roles of local heating and conductive energy gain in the transition region in a self-consistent way. For example, a recent study based on 3D MHD models suggests that plasma from the chromosphere to the corona in active region plages is heated through energy dissipation in local current sheets. However, this might not be the case in general. Using similar models together with simplified analytical considerations, we find that the heat conduction might well dominate the heating of the transition region when loop temperatures reach above 3 MK and the heating scale length is large. Thus, the decade-old problem does not admit a simple yes-or-no answer, but requires detailed and quantitative analysis of the underlying heating mechanisms in different solar magnetic environments.

On the "cool" origin of nanojets

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Oral

The topological dissipation paradigm, as originally proposed by Eugene Parker, envisions the continuous buildup of magnetic energy through photospheric motions and its frequent, impulsive release through reconnection-driven nanoflares. Numerical models predict that sideways-propagating reconnection outflows are a natural consequence of small-angle magnetic reconnection in structures dominated by a strong guide magnetic field, such as coronal loops. Observations of nanojets have recently been identified as a smoking-gun signature of this process, providing a key diagnostic to probe the elusive physics of nanoflares. However, several fundamental questions remain open: Why are nanojets most often observed as single-sided jets? What physical conditions enable their multi-band visibility? Why are nanojets preferentially observed in environments where cold and dense plasma is present? Here we present 3D MHD simulations that self-consistently reproduces many key observational properties of nanojets and provides a framework in which the morphology, dynamics, and detectability of nanojets depend sensitively on the thermodynamic environment of magnetic reconnection. In particular, the simulations indicate a "cool" origin for coronal nanojets, interpreted as subclass of reconnection outflows, where dense, cold plasma enables narrow, multi-band jet signatures to emerge from reconnection outflows.

The evolution of the coronal loop structure due to the phase mixing of high and low-frequency Alfven waves

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Oral

Phase mixing of Alfvén waves in coronal loops has long been considered a candidate to (partially) address the coronal heating problem. However, it has been argued that some of the coronal loop models used to study wave heating are not self-consistent, as the heating generated by the phase mixing of Alfvén waves may be insufficient to maintain the density structure required for phase mixing. Using 2.5D simulations of driven Alfvén waves, we find that low-frequency waves are unable to be effectively dissipated, resulting in minimal changes to the loop structure. We see little evidence of wave energy accumulation in the corona and are unable to conclude that the dissipation of low-frequency Alfven´ waves can be an effective heating mechanism in coronal loops in the setup used in this study. On the other hand, we show that high-frequency waves can generate heating corresponding to a ∼10% increase of the initial coronal shell temperature, chromospheric upflows of up to 0.6 km/s and a coronal shell mass increase of ∼15%. These changes are sufficient to alter and maintain a new coronal loop density structure, broadening the region where efficient phase mixing (and therefore heating) occurs. We show that phase mixing of high-frequency Alfvén waves in the shell region can fully offset a small decrease in the background heating profile, and that the thermodynamic feedback is sufficiently large to affect the density profile, broadening the region where efficient heating occurs. When the heating function is removed completely, a sharp decrease in density occurs, and the system becomes a complex interplay between the dissipated wave energy, reduced energetic losses, and decreased plasma thermal capacity. Heating in the shell region is shown to be sufficient to slow the rate of density decrease, leading to the shell density overtaking the interior density and forming a two-peak cross-field density profile.

The Multi-slit Solar Explorer (MUSE)

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In this talk I will discuss the upcoming Multi-slit Solar Explorer (MUSE) mission, which is scheduled for launch in 2027. MUSE is a NASA MIDEX mission, composed of a multi-slit EUV spectrograph (in three narrow spectral bands centered around 171Å, 284Å, and 108Å) and an EUV context imager (in two narrow passbands around 195Å and 304Å). MUSE will provide spectral and imaging diagnostics of the solar corona at high spatial (0.5 arcseconds), and temporal resolution (down to 0.5 seconds) thanks to its innovative multi-slit design. By obtaining spectra in 4 bright EUV lines (Fe IX 171Å, Fe XV 284Å, Fe XIX-XXI 108Å) covering a wide range of transition region and coronal temperatures along 35 slits simultaneously, MUSE will be able to "freeze" (at a cadence as short as 10 seconds) with a spectroscopic raster the evolution of the dynamic coronal plasma over a wide range of scales: from the spatial scales on which energy is released (¡0.5 arcsec) to the large-scale often active-region size (170 arcsec x 170 arcsec) atmospheric response. I will provide an update on the status of MUSE, including numerical simulations illustrating how MUSE observations can help address outstanding questions regarding coronal heating. I will also describe the multi-slit data approach and the data products that the MUSE team will provide.

Magnetic Field Line Mappings and Field-Aligned Integrals as a Dimensionality-Reducing Tool to Analyze 3D Models of Coronal Heating and Loop Hydrodynamics

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Poster

Modern studies of coronal heating often involve conducting magnetohydrodynamic (MHD) or field-aligned hydrodynamic (HD) simulations of realistic magnetic field configurations in 3D. Incorporating a realistic surface flux-distribution into the modeling generally implies complex connectivities and a wide-range of loop properties in the volume-filling 3D coronal field (length, field strength, areal expansion). Given the wealth of information present in a time-evolving 3D model, it can be useful to seek ways to capture the essence of the magnetic field and plasma state in a reduced dimensional form. In this presentation, we overview several ways in which field-line mappings and associated field-aligned integrals can accomplish this goal. Using a high-resolution field-aligned HD simulation of an active region and a data-driven MHD model of the global corona as examples, we illustrate how such mappings can be used to characterize: (1) the basic connectivity and topology of a region; (2) average loop properties and statistics, which can be related to coronal heating scaling laws; and (3) the time-evolving nature of loop heating and cooling cycles. Although many of the mapping techniques are not fundamentally new, our goal is to collect these ideas in one place, discuss the finer points of how different weightings conserve (or not) certain properties, and demonstrate how they can be a useful tool in our toolbox for characterizing modern coronal heating simulations. These methods in will also be available in upcoming releases of our open-source field-line tracing codes for spherical geometries in Fortran (MapFL) and python (mapflpy), available on GitHub.

Understanding how Coronal Heating Affects Global Properties of the Low and Middle Corona

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Oral

The magnetic field of the Sun is a key driver of coronal heating and solar wind acceleration. In tandem, these influence the plasma properties and observable morphology of the corona, along with defining the magnetic connectivity and magnitude of open magnetic flux. Here, we choose to investigate how coronal heating affects the magnetothermal state of the 3D global corona by analyzing a series of data-constrained, thermodynamic magnetohydrodynamic (MHD) simulations for solar minimum conditions. We vary the overall heat deposited in the corona via modifying the input Poynting flux of a wave-turbulence-driven (WTD) model for coronal heating and by scaling the inner boundary magnetic field. We quantify the magnetic, thermodynamic, and combined magnetothermal effects on our simulations. We find that increasing the overall amount of heat leads to a higher magnitude of open flux and a more visibly open white light morphology in the K-Corona between 1.5 and 6 solar radii. We quantify how plasma beta evolves and drives morphological differences between simulations. We also compare these runs to an extremely high-resolution reference solution that includes small-scale magnetic information in the surface boundary condition. This latter comparison provides insight into the further development of 'subgrid' corrections for low(er) resolution models to best represent the structure and observables of the corona and inner heliosphere.

Thermal non-equilibrium cycles in a pseudo-streamer

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Poster

Thermal non-equilibrium (TNE) is a well known thermodynamic mechanism in coronal loops. These evaporation and condensation cycles are induced by a quasi-steady stratified heating. Long-period EUV pulsations and coronal rain are two manifestations of TNE. The quasi-periodicity of the cycles is a strong characteristic of TNE: the system dynamically evolves around an equilibrium position that is not reachable.

There are recent reports of coronal rain at open-closed boundaries such a fan-spine topologies and pseudo-streamers. However, no definite conclusions were drawn on the physical mechanisms driving the coronal rain events. In our study, we report the detection of long-period EUV pulsations and co-spatial periodic coronal rain showers in a pseudo-streamer observed with SDO/AIA. The magnetic topology and evolution of the pseudo-streamer are studied into details, using a combination of PFSS modeling and EUV dynamics. The event that last for 2.5 days shows all the characteristics of previous TNE events reported in coronal loops.

We further show that these TNE cycles occur not only in the closed field but also in the open field. Our observations support the findings of recent numerical works. In parallel, interchange reconnection occurs continuously and non impulsively all along the open-closed boundary as seen in EUV. Our work opens further perspectives for the understanding of TNE in the solar atmosphere and its potential implication for the solar wind.

Energy subfluxes in Reduced MHD

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Poster

Many complex dynamics observed in the solar corona as well as in a broad range of astrophysical, industrial plasmas and magnetofluids are well described by the MHD equations. However, due to this inherent complexity, further assumptions are often required to gain results with available resources. A coronal loop, similar to many plasmas, is characterised by a strong magnetic field. This is a natural choice for simplifying the MHD equations. When making additional assumptions, how do we know which dynamical processes are retained and which are lost? How do we know which processes are important for a particular system? To identify these physical processes governing energy transfer to small scales we leverage an energy flux decomposition, that has recently been extended from hydrodynamics to MHD. This technique provides a clear framework to identify the processes present in 3D incompressible MHD by splitting the energy flux into subfluxes that originate from vortex stretching, strain self-amplification, current-sheet thinning and current-filament stretching, and to quantify their contribution to the energy cascade. In this talk we apply this approach to the approximation of Reduced MHD (RMHD). This model is described as a nonlinear, low-frequency incompressible approximation to 3D compressible MHD. RMHD correctly illustrates many known features of the strong mean-field limit of MHD, but clearly does not capture all of the dynamics present in the MHD equations. In this talk we will take the first step to address this by identifying the main processes present in RMHD and compare this to MHD.

Tearing instability evolution

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A potential coronal heating mechanism involves the slow storage of magnetic energy in the coronal magnetic field which is then rapidly released. For example, coronal loops can be slowly stressed by sub-surface, convective motions. Then, instabilities, such as the resistive tearing, can subsequently lead to reconnection and the release of the stored magnetic energy. Here, we focus on how to model the slow energy storage phase and the initial release of energy.

It seems natural that the process of storing and releasing magnetic energy can occur in a cyclic manner, with the system evolving through sequences of equilibria. However, previous simulations, using the approximate method of Reduced MHD (RMHD), have shown that this process only happens once, after which the system remains in a statistically steady turbulent state and magnetic energy does not build up again.

In this talk we use 3D compressible MHD simulations to investigate the dynamics of the tearing mode instability. A modelled coronal loop is subject to continuous footpoint motions involving a steady shearing and an additional perturbation in the form of kink waves. The applied steady shearing motion results in the creation of current sheets and the kink waves perturb the system, resulting in the onset of the tearing instability, leading to the formation of magnetic islands and reconnection.

The solar atmospheric response to coronal heating around magnetic null points

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Magnetic null points are fundamental components of the complex solar atmosphere, facilitating magnetic reconnection, MHD wave mode conversion and, promoting energy release and plasma heating. As a result, they can play an important role in the solar atmospheric energy cycle and are associated with thermodynamic conditions which differ significantly from the surrounding plasma. In this talk, I will present the results of numerical, 2.5D, MHD simulations of a magnetic arcade embedded within a gravitationally and thermally stratified solar atmosphere with a magnetic null point located above the apex of the closed coronal loops. I will examine the impacts of this null point on the energisation of the coronal magnetic field in response to both steady shearing and oscillatory driving. By comparing these distinct regimes, I will quantify differences in energy injection rates, small scale formation, the efficiency of energy release and heating, as well as the subsequent response of the atmosphere. In the context of the workshop theme, I will also explore how magnetic reconnection at the null restructures the coronal field and use synthetic emission diagnostics to discuss the observational implications of these simulation results.

Self-Consistent Heating of the Magnetically Closed Solar Corona: Generation of Nanoflares, Thermodynamic Response of the Plasma and Observational Signatures

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The energy that heats the magnetically closed solar corona originates in the complex motions of the massive photosphere. Turbulent photospheric convection slowly displaces the footpoints of coronal field lines, causing them to become twisted and tangled. Magnetic stresses gradually build until reaching a breaking point when the field reconnects and releases a sudden burst of energy. We simulate this basic picture of nanoflares using a high-fidelity, three-dimensional, multistranded magnetohydrodynamic simulation that starts with a fully stratified atmosphere. This simulation includes the effects of field-aligned thermal conduction and optically thin radiation and uses the state-of-the-art Transition Region Adaptive Conduction (TRAC) method to capture the response of the plasma to the nanoflare heating. We find that our physical model supports a unified explanation for both the diffuse emission observed in active regions and the bright coronal loops. Specifically, our results suggest that the diffuse emission originates from spatially and temporally uncorrelated nanoflares, whereas coherent clusters of nanoflares—nanoflare storms—are responsible for the formation of bright coronal loops. Quantitative comparisons between the simulated emission and observed characteristics of coronal loops show that key observed properties—such as loop widths, lifetimes, and cross sections—are reasonably well reproduced by the model. The idea that avalanche spread naturally leads to circular cross sections in loops is strongly supported. Our results also suggest that phase differences in heating and cooling events across neighboring magnetic flux strands are a plausible explanation for the anomalous cross-field motions of coronal loops that were recently reported in high-resolution observations.

Forward modelling MUSE observables of MHD waves in a coronal loop

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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.

Thermal instability in coronal loops: linking eigenvalue spectra to time-dependent evolution

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Cool, dense condensations such as coronal rain and prominences indicate that coronal plasma can undergo runaway radiative cooling. To link this behaviour to linear thermal modes, we study how eigenvalue spectra map onto time-dependent evolution.

We analyse a simplified, coronal-only stratified loop model by combining spectral analysis, linear initial-value simulations, and nonlinear simulations of the same 1D setup.

We study waves and instabilities, as well as temporal evolutions for a 1D hydrostatic, thermally balanced loop with optically thin radiation and prescribed heating. The non-adiabatic spectrum of all the physically realisable eigenmodes is computed with our open-source code Legolas. We demonstrate our newly developed boundary value-initial value solver called Legolas-IVP, where linear evolutions are performed for controlled perturbations, and fully equivalent nonlinear runs are carried out with our generic software toolkit MPI-AMRVAC.

The stratified loop spectrum contains discrete acoustic modes and a thermally unstable branch consisting of thermal modes, including a thermal continuum. Linear initial-value experiments show how mode polarisation determines which perturbations efficiently trigger thermal growth. Already in the linear stage, thermal imbalance drives siphon-like flows from the footpoints toward the cooling region. Growth rates measured with LEGOLAS-IVP agree with spectral predictions and are reproduced in MPI-AMRVAC.

This investigation for the simple 1D loop demonstrates a direct link between thermal eigenmodes and time-dependent condensation dynamics, and provides a basis for extending such mode-based interpretations to fully 3D magnetohydrodynamic models.

A Fresh Look at Coronal Heating Scaling Laws

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Scaling laws relating the volumetric coronal heating rate to physical parameters such as magnetic field strength and field line length are commonly used in 0D and 1D hydrodynamic models (loop models) and 3D models of active regions and the global corona. Often these scaling laws are based on idealized coronal heating theories. Typically missing, however, are dependencies on magnetic field expansion, large-scale current density, large-scale field inclination at the base, and photospheric driver velocities. In this talk, I will discuss these neglected and potentially important effects.

A self-consistent solar coronal heating model by Alfvenic waves

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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. 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 all 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 Alfven wave turbulence-based models used in space weather and stellar activity modeling, such as the Alfven Wave Solar Model (AWSoM) and the Magnetohydrodynamic Algorithm outside a Sphere (MAS).

Study of thermal non-equilibrium in a 3D hydrodynamic simulation of an active region and comparison with EUV observables

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Thermal non-equilibrium (TNE) is a common feature of active-region loops. TNE consists of cyclic plasma evaporation and condensation driven by a highly stratified and quasi-steady heating. Long-period (several-hours) EUV pulsations and coronal rain are two observables linked to these periodic variations in coronal temperature and density. However, the bias of current Fourier-based detections toward ideal cases hinders accurate evaluation of the coronal volume undergoing TNE cycles, a key parameter for coronal heating models.

Based on a 3D hydrodynamic simulation (MAS) and synthetic observations of AR 11139, we aim to determine: (1) the fraction of the active-region volume subject to TNE cycles, and (2) the proportion of these cycles that can be detected in synthetic EUV observations.

To address these questions, we adapt the method of Auchère et al. 2014 in order to detect 3D temperature and density periodicities. We identify regions exhibiting TNE in the volume of the active region and compare them with those of long-period EUV pulsations.

A significant part of the AR volume (between 30% and 50%) undergoes TNE cycles, mostly in coronal loops. This result is most likely model-dependent, estimating the TNE volume in an active region could therefore serve as a novel method to discriminate heating models. However, not all the cycles are detected in the synthetic observations, especially when there are multiple TNE cycles along the line-of-sight. We conclude that the current observational studies may greatly underestimate the volume occupied by TNE.

Spatio-Temporal Evolution of a Long-lived Supersonic Downflow above a Sunspot

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Super-Sonic Downflows (SSDs) are usually observed above sunspots as redshifted components in the Transition Region (TR) spectral lines and have lifetimes of a few minutes to several hours. We investigate short-term dynamics of a long-lived SSD above in active region 12135 using Interface Region Imaging Spectrograph (IRIS) observations to better understand the spatio-temporal evolution of these flows in the sunspot's atmosphere. Triple Gaussian fitting with specific constraints at each pixel of the TR spectral lines, along with Non-Force Free Field (NFFF) extrapolation, is performed to study this event. We find that downflow is initially observed in both the umbral and penumbral regions. Over time, the penumbral downflow fades, while the umbral downflow strengthens and appears as a single structure that eventually splits into two spatial segments. NFFF extrapolation indicates that a fan-spine magnetic topology is present near the sunspot. As suggested by the brightening observed in Atmospheric Imaging Assembly (AIA) 171 images and the topology change indicated from extrapolations, magnetic reconnection near this site is the most probable cause of this splitting. Before the splitting event, a rare anomalous motion of the loop's footpoint in the sunspot's atmosphere is observed in both IRIS spectroscopic and imaging channels. The average calculated properties, including downflow speed, electron density, and mass flux for this event, align with established studies. By combining IRIS spectroscopic observations with imaging data from different AIA filters, our analysis revealed that changes in the downflow's morphology are linked to alterations in the coronal loops' structure.

Decay Lengths of Propagating Slow Waves in Coronal Fans with Simultaneous SDO/AIA and SolO/HRIEUV Observations

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Slow magnetoacoustic waves are common in coronal plasmas and serve as valuable diagnostics for coronal seismology. Despite their ubiquity, the decay lengths of these waves remain poorly understood, with measured values often significantly shorter than theoretical predictions and substantial discrepancies between instruments.

To address this gap, we use coordinated SDO/AIA and SolO/HRIEUV observations to investigate the decay lengths of propagating slow waves in sunspot-anchored coronal fans. We analyse two events: one where the spacecraft observes the same active region at a separation angle of 16.2°, and another with almost parallel (2.0°) lines of sight. Using time–distance analysis, we determine wave periods, projected phase speeds, and decay lengths for several individual feathers.

The observed oscillations have dominant periods in the 3-minute band and projected phase speeds consistent with slow magnetoacoustic waves. Notably, when the spacecraft observe from nearly parallel lines of sight, the decay lengths measured with AIA and HRIEUV agree closely. In contrast, when the viewing geometry differs significantly, the decay lengths differ substantially between the two instruments.

Taken together, these results illustrate that the measured decay of slow waves is strongly influenced by viewing geometry and line-of-sight effects. Consequently, observational effects must be carefully considered when using decay-length measurements to constrain physical damping mechanisms in the solar corona.

Hinode EIS Observations of Plasma Composition Evolution and Radiative Cooling of Solar Flare Loops

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Plasma composition in flaring regions has been shown to have significant spatial and temporal variations, likely driven by dynamical processes that take place as a consequence of the sudden energy release at the reconnection site. The origins of these variations, as well as the effects they might, in turn, have on flare loops dynamics are not yet fully understood. In this work, we investigate the link between flare loop cooling times and plasma composition evolution in the loops formed during the M-class flare peaking at 13:56 UT on the 2022 April 2 using high cadence Hinode EIS spectroscopic observations. The analysis focuses on quantifying the cooling rate (using a series of emission lines covering a wide temperature range) and plasma composition evolution (using the Ca XIV 193.866 A/Ar XIV 194.401 A diagnostic) at the apex and footpoint of the flare loop arcade. Results show slower cooling and a FIP bias of 2.4 $\pm$ 0.2 in the loop footpoint and faster cooling and a stronger FIP bias of 2.8 $\pm$ 0.2 in the loop apex. The potential effects of plasma composition changes on the radiative cooling process of flare loops are also investigated by comparing observed loop cooling times to those predicted by simulations from the EBTEL 0D hydrodynamic model. The EBTEL simulations show that an higher FIP bias would lead to a faster radiative cooling rate and, therefore, shorter cooling times. This suggests that the variation in FIP bias observed in the two features could be responsible for the different cooling times observed.

Distinct Regimes of Turbulent Reconnection: A New Trigger for Fast Coronal Energy Release?

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Oral

Magnetic reconnection is a key process for releasing energy in coronal loops and flares. Recently, 3D direct numerical simulations of turbulent reconnection have shown that locally coherent flux ropes play a role similar to that of plasmoids, producing a reconnection rate of about 0.01 in MHD, or 0.1 with kinetic physics. However, this picture applies when a guide field is present. This talk presents discovery of a distinct regime, in the absence of a guide field, i.e. in the limit of strong shear. In this new regime, self-generated turbulence becomes the dominant driver of reconnection. Coherent local flux ropes do not form; instead, short-wavelength instabilities arise that interchange field lines across the current layer, allowing turbulence to significantly broaden the reconnection region and raise the MHD reconnection rate to about 0.03. This is substantially faster rate in the zero-guide-field (anti-parallel) case, is likely to have different energisation properties, and provides a novel mechanism for explaining the sudden switch to fast reconnection in the solar corona.

Resonant cavity effects on slow wave spectra in the sunspot corona

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Oral

Chromospheric resonances above sunspot umbrae have been measured in observational and numerical studies. The coronal power spectra of slow magnetoacoustic waves above sunspots have been attributed to the acoustic cut-off frequency, the chromospheric resonance cavity bounded above by the transition region, or a combination of both. It is well established that wave reflections with height in the lower sunspot atmosphere facilitate the formation of the resonant cavities. However, the connection between the wave driver, the cut-off frequency, and the resonant cavities remains unclear. We perform 2.5D magnetohydrodynamic numerical simulations on different slices of the same sunspot configuration to investigate the response of the systems to different monochromatic acoustic drivers as well as a single-pulse driver. The resonant cavity is identified to be in the upper chromosphere of the sunspot simulation setup. Single-pulse driving shows that the chromospheric resonance cavity excites a broadband of frequencies rather than a single dominant mode. In the case of monochromatic driving, the dominant resonant frequency is influenced by the driving frequency due to tunnelling effects. Continuous driving imposes an additional dominant frequency on top of the natural resonance, which is reflected in the overall shape of the coronal power spectra of slow waves. A two-dimensional investigation of the radial dependence between magnetic field lines in sunspot umbrae reveals cross-field communication between magnetic field lines within the resonance cavity.

Convective Origins of Alfvénic Waves in the Solar Atmosphere: Insights from DKIST

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Oral

A fundamental question in solar physics is what drives the ubiquitous Alfvénic wave field observed throughout the solar atmosphere. These waves carry sufficient energy to heat the corona and accelerate the solar wind. Yet their origin, whether rooted in convective motions at the photosphere or in localised energy release through magnetic reconnection, has remained a matter of active debate. Resolving this question is critical not only for coronal heating models, but for understanding how wave energy is injected at the base of coronal loop structures and subsequently propagates and dissipates.

Here we present results from high-resolution observations with the Daniel K. Inouye Solar Telescope (DKIST), which, for the first time, provide the spatial and temporal resolution necessary to directly confront these competing hypotheses. Our findings demonstrate that convective granulation is the dominant driver of Alfvénic wave energy in the solar atmosphere, with the buffeting and shearing of magnetic footpoints by granular flows generating a broadband spectrum of transverse fluctuations that propagate upward into the chromosphere and corona. Reconnection-driven mechanisms, while present, appear to play a secondary role in the overall wave energy budget.

Considering the Effects of Optically Thick Radiation in Cool Coronal Condensations

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Oral

The formation of cool coronal condensations, such as prominences and coronal rain, in coronal loop structures through different processes (including thermal non-equilibrium cycles), has been studied at length. Whilst the trade-off between optically thin radiative losses (at high temperatures), and thermal conduction are key to forming these structures, as they cool below 30 kK partial ionisation and optical depth effects become important. The former of these significantly reduces the pressure for a given mass density and temperature over what is predicted by the ideal gas law, whilst the latter can dramatically increase the radiative losses whilst out of equilibrium but also provide an energy source term potentially helping to stabilize structures.

Recent work has shown that in static radiative models, including the effects of non-equilibrium ionisation and optically thick losses in the cooling of these structures temporarily produces temperatures much cooler than those predicted by an instantaneous relaxation to ionisation equilibrium, before a slow reheating phase towards radiative equilibrium state. Here, we present initial 1D radiation hydrodynamic and 2.5D radiation magnetohydrodynamic models of cool coronal condensations considering detailed optically thick radiative losses and non-equilibrium ionisation. We discuss some implications for the stability of these structures as well as considerations for spectroscopic diagnostics.

MHD simulations of Nanojet with magnetic resistivity or viscosity

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Oral

Magnetic reconnection in the solar corona is expected to generate impulsive, small-scale heating events—nanoflares—whose collective contribution may sustain the coronal temperature against conductive and radiative losses. Recent observational and numerical studies have identified nanojets as the dynamic byproducts of reconnection, offering a potential proxy for the elusive nanoflare population. A key open question is how the physical properties of nanojets, in particular their heating efficiency and kinematics, depend on the nature of the underlying dissipation mechanisms. In this work, we investigate how resistive and viscous processes modify the evolution of nanojets and the associated thermal and dynamical signatures of reconnection. Using 3D MHD simulations, we investigate the resistivity and viscosity to probe their role and by comparing these regimes, we aim to establish whether nanojet observables—such as temperature enhancements, velocities, and morphological characteristics— can give away the underlying dissipative effect. Our results can provide guidance on which nanojet properties are most sensitive to the underlying dissipation physics, thereby informing future observational strategies and helping to extend nanojet-based nanoflare detection from controlled MHD experiments to the solar corona itself.

Sloshing Oscillations in coronal loops excited by successive M- and C-Class Flares

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Oral

Loops associated with flares often exhibit plasma oscillations, where a disturbance moves back and forth between the loop footpoints. These oscillations are known as sloshing oscillations. Current understanding suggests that they are triggered by flares; however, they do not appear after every flare. Moreover, the connection between flare strength and the occurrence of oscillations is still not well understood. To investigate the impact of successive flares of different classes on the properties of sloshing oscillations, we analyzed these oscillations triggered by successive M- and C-class flares using the data of AIA onboard SDO. A total of 15 sloshing oscillation cases were identified within seven distinct coronal loops. The properties of the oscillations were primarily derived from the AIA 131 and 94 Å channels, where the oscillatory signatures are clearly visible. Additionally, we estimate the deprojected length of each loop by assuming a semi-circular geometry. The oscillation periods in our sample range from 300-600 s for coronal loops with lengths between 70-210 Mm. The corresponding loop temperatures span 9-30 MK, while the damping times lie in the range of 130-1700 s. Our results suggests that the properties of oscillations within the same coronal loop can vary significantly from one flare to another, suggesting the role of individual flare in shaping up the local physical conditions. The scaling between period and damping time follows a power law relation with exponent of 1.37 ± 0.07 in 131 Å and 1.50 ± 0.10 in 94 Å channel. We also find a linear scaling between the oscillation period and loop length.

Solar Orbiter High Resolution Imager Reveals Unprecedented Fine-scale Structures in Solar Flare Ribbons in the Corona

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Oral

We report unprecedented observations of fine sub-structures within a flare ribbon in the lower solar corona. During its perihelion on 30 September 2024, Solar Orbiter observed an M7.7-class flare with its suite of instruments from a distance of 0.29 au. We measure the physical properties of EUV -riblets—narrow structures that appear to channel small-scale downflows within the flare ribbon. The widths of these sub-structures are of the order of 100 km, making them among the smallest features identified during magnetic reconnection in the solar corona. The width distribution suggests that these structures are not self-similar, but may instead arise from an underlying multiplicative or stochastic process. The EUV riblets exhibit downflow velocities ranging from 30 to 100 km/s, while the flare ribbon itself—together with the embedded sub-structures—moves laterally at approximately 8.2 km/s. This propagation speed initially decreases and later increases to more than twice its earlier value as the flare evolves. During this interval, an enhancement in X-ray emission is observed, indicating the presence of ongoing multiple reconnection events. The observation of coronal-temperature plasma (1 MK) flowing downward in narrow EUV riblets, even during the rising phase of the flare, is reported here for the first time. These results suggest that large-scale flares may be sustained by complex magnetic energy release processes operating on very small spatial scales.

The Impulsive Coronal Heating Event Distribution of an Active Region From 3D Simulation of its Emission

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Oral

The heating of closed magnetic loops in the solar corona remains one of the key unsolved questions in solar physics. Impulsive energy release at small spatial and temporal scales has been a leading candidate mechanism for decades, but has proven difficult to confirm observationally, in part because the signatures of individual events are below current instrumental resolution. Here, we present a simulation framework, driven by data-driven 3D spatial reconstruction, that reproduces the visual appearance of an observed active region both spatially and temporally. We find that reproducing the temporal variation (dynamics) of the region requires a heating event distribution with significant energy in the nanoflare range, which we assess quantitatively via the distribution of detected brightenings in real and simulated data. We also perform an initial investigation of steady heating with Thermal Non-Equilibrium (TNE) as an alternative to nanoflare-scale heating events. These results demonstrate a broadly applicable methodology for constraining coronal heating models in realistic active region geometries.

High-order multi-fluid modelling of coronal loops: collision-mediated FIP fractionation of heavy elements

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Poster

Coronal abundances constitute a key parameter in studies of active region loops, and yet they show anomalies that are poorly understood. They are usually fixed to pre-defined values when diagnostics are made from coronal spectral lines such as the widely used differential emission measure (DEM), with values that do not necessarily reflect the observed region. They also influence drastically the amount of radiative losses in the optically thin corona, losses which affect in turn the whole thermodynamics of the loop including the formation of thermal non-equilibrium (TNE) cycles and coronal rain. Understanding the origin of those abundance anomalies involves the necessity of having multi-fluid numerical models able to solve all species (neutrals, ions and electrons) together. Because collisions are strong in the chromosphere where abundance anomalies start to appear, all those transport equations need to be resolved in a fully coupled manner. We present some of the last results obtained with the multi-fluid ISAM code which has received substantial improvements over the last year. They include in particular a more realistic treatment of photoionisation and radiative cooling/heating in the chromosphere. Our results show that collisions play a key role in the formation of those anomalies, where species do fractionate according to their first ionisation potential (FIP) as seen in observations. No special tuning was necessary with the simulations being mostly parameter-free, at the exception of the loop geometry and plasma heating conditions. Our level of enrichment for low-FIP species like Magnesium and Iron is consistent with statistical values derived from observations. However, the high-FIP Neon specie would require additional modelling efforts to agree with the observations. In that regard, we stress out that this model constitutes only a first step towards unifying collision based processes with wave theories. Although wave based theories have received an extensive attention recently, the relative contribution of waves with respect to collisions in the generation of abundance anomalies still needs to be quantified.

Distribution of energy release events due to magnetic braiding in coronal loops

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Oral

Energy conversion by reconnection-powered nanoflare heating is one of the leading explanations for the heating of the solar chromosphere and corona. The aim of this study is to shed light on this mechanism by exploring the magnetic Reynolds number dependence of the energy conversion process. To do this we employ boundary-driven, magnetohydrodynamic, flux-braiding simulations at different magnetic Reynolds numbers (R_m), and explore in detail the properties of the individual magnetic energy release events. The properties of the reconnecting current sheets that mediate the energy release are shown to depend on R_m. For increasing R_m, the current sheets become thinner, more intense, and more numerous. For sufficiently large R_m, the current sheets fragment along their length, leading to a sharp cutoff in the current sheet length distribution. The cutoff is consistent with the threshold for non-linear tearing/plasmoid instability. For increasing R_m the magnetic field lines become increasingly tangled, the mean and peak values of the magnetic field strength increase, and the Poynting flux into the domain increases, implying that the heating rate also increases. The global reconnection rate is essentially independent of R_m. These results support the braiding mechanism as a viable way to effectively heat the internal portions of coherent flux tubes in the corona.

Exploring small-scale coronal loop structures using ultra high resolution observations from Hi-C Flare

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Oral

This work takes advantage of new observational data collected by the High-resolution Coronal imager (Hi-C) at the highest spatial and temporal resolutions available. This most recent Hi-C dataset is the first to make use of the hot 129A channel and the first to consist of targeted observations of a solar flare, rather than the quiescent corona. Images from Hi-C are analysed and compared with complementary EUV observations from SDO/AIA. The widths of the loop strands are measured, and the resulting populations analysed. There is some evidence that there are smaller structures present which are partially resolved by Hi-C, with the very smallest smallest loop strands of a similar order of magnitude to the spatial resolution of the Hi-C images. Further results will be presented, as well as a discussion of future work, investigating individual events within the Hi-C observations, making use of the high cadence available to track the dynamic behaviour of the corona.

MHD Coronal Loop Modeling and the Scaling of Loop Plasma Properties With the Ambient Magnetic Field

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Oral

Using three-dimensional magnetohydrodynamic (MHD) simulations of kink-unstable coronal flux tubes, we investigate how the intensity of the ambient magnetic field influences the thermal regime of coronal loops. The simulations, performed with the PLUTO code, explore field strengths between 10 G and 80 G under continuous photospheric twisting that drives magnetic reconnection and heating through anomalous resistivity. After an initial transient, the system reaches a statistically steady state characterized by persistent nanoflare-like energy release. We find that the differential emission measure (DEM) distribution increases in magnitude and shifts to higher temperatures with increasing magnetic field strength, while being largely insensitive to other parameters such as the resistivity and resolution. Extending the classical Rosner–Tucker–Vaiana (RTV) scaling laws, we derive a scaling relation for the loop temperature, which quantitatively matches the simulation results. This study demonstrates that the strength of the ambient coronal magnetic field is the primary factor determining the thermal state of coronal loops, providing a physically grounded connection between magnetic field measurements and observed coronal temperatures.

Turbulent magnetic reconnection in braided coronal loops

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Oral

Magnetic reconnection has a key facilitative role in heating coronal loops, as well as in altering the topology of the magnetic field. As such, it is desirable to be able identify the locations at which it occurs, the properties of reconnection sites, and the nature of the change in magnetic connectivity in complex coronal magnetic fields. In order to do so, we perform a detailed analysis of a three-dimensional braided magnetic field in which simple, ordered boundary motions applied to a multi-stranded coronal loop bring about instabilities that lead to ongoing magnetic reconnection. Reconnection occurs at sites away from the traditional locations of null points, separators, and quasi-separatrix layers, and thus we find a distinctive new mode of three-dimensional reconnection. Statistically, the sizes of reconnection sites follow a power-law distribution. Geometrically, these sites are elongated along the direction of the magnetic field, in long, narrow, loop-aligned current sheets. Typically, field lines reconnect with a small, but significant angles of misalignment between them. Reconnection takes place effectively continuously, with individual field lines seen to reconnect several times along their lengths in very short intervals in time, as they pass through many small current concentrations. We illustrate the flipping of the footpoints of reconnecting field lines, as well as their three-dimensional interaction. Overall, we find magnetic reconnection in turbulent, braided loops to be more complex and subtle than has previously been discussed, and to have characteristics very different from those of previous models.

Revisiting the observed constant width of coronal loops with magnetic field extrapolations

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Oral

The high-resolution observations of 1-2 MK coronal loops in EUV have shown a puzzling behaviour: the width of a loop is fairly constant. Knowing that the magnetic field strength decreases with height, these observations contradict the basic principle of frozen flux or flux conservation along a flux tube as a direct consequence of the Maxwell's equations. We revisit this concept from a different view point: starting from the statistical values of coronal loop widths (Williams et al. 2021, ApJ, 919, 47), we use magnetic field extrapolations to determine the expected width of the loop at the footpoint. We analyse a large sample of field lines from different active regions and different locations (i.e. umbra, penumbra, plage). The gradient of magnetic field strength along the loop near the apex being smaller than near the footpoint, the loop expansion/width is small and almost undetectable near the apex. This approach also provides constraints on the size of isolated flux tubes and thus of electric currents in the photosphere: a sunspot is typically made of a large number of isolated flux tube near or below the detection limit of current instrumentation.

Ion Temperatures in Solar Flares and Reconnection Heated Coronal Loops

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Oral

This presentation argues that the ion temperature is several times the local electron temperature in the hot onset phase and in the above-the-loop region of solar flares, and considers the wider implications for species temperatures in coronal loops heated by magnetic reconnection. Specifically we consider: the evidence of spectral line widths ("nonthermal" broadening); evidence for "universal" ion and electron temperature increase scaling relations for magnetic reconnection in the solar wind, Earth's magnetopause, Earth's magnetotail, and numerical simulations; and thermal equilibration times for typical coronal densities. For flares, we conclude that the ion temperature is likely to reach 60 MK or greater and that it may represent a substantial part of spectral line widths, significantly contributing to solving the long-standing issue of the excess nonthermal broadening in flare lines. We suggest that ions with temperatures up to 6.5 times the electron temperature may similarly be present in reconnection-heated coronal loops.

Related paper: Russell et al. (2025) ApJ Letters 990:L39 Key ideas in this work were stimulated by discussions at the 2024 Coronal Loops Workshop

Wave Propagation in Horizontally Stratified Two-Layer Polytropic Model

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Poster

Gravity modes (g-modes) provide an important diagnostic of stellar interiors, yet their interaction with magnetised atmospheric layers remains poorly understood. This work investigates buoyancy-driven magnetohydrodynamic (MHD) waves in a horizontally stratified atmosphere using a two-layer model that couples a non-magnetic polytropic layer representing the solar interior with a magnetic isothermal layer modelling the solar atmosphere. The analysis is performed within the Boussinesq approximation with a horizontal magnetic field perpendicular to gravity, allowing analytical derivation of the governing equations, eigenfunctions, and dispersion relations.

Analytical and numerical analysis of the dispersion relation reveals two distinct solution branches: a buoyancy-dominated branch corresponding to g-type slow modes and a magnetically dominated branch that appears at larger horizontal wavenumbers. The results also show that wave propagation is constrained by frequency cut-offs governed by the Alfvén speed and the Brunt–Väisälä frequency. These findings highlight how atmospheric magnetic fields modify gravity-wave dynamics and influence the coupling between solar interior oscillations and the magnetised solar atmosphere.

Wave-driven cross-field density transport in structured coronal-loop plasma

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Poster

Coronal loops are commonly modelled as magnetically confined plasma structures whose evolution is primarily field-aligned, with crossf ield transport assumed to be weak. Here we explore a complementary possibility: that Alfvénic fluctuations propagating along a transverse density gradient can generate density perturbations that drive a net cross-field transport of mass. We consider an idealised, non-expanding Cartesian domain with a straight background magnetic field, no curvature or flow, and a prescribed sinusoidal transverse density profile. Alfvén waves are launched along the field direction with $k_\perp \gg k_\parallel$ allowing us to isolate the response of the density structure to wave-driven motions and to measure the rate at which the imposed structure relaxes. We compare the simulation results to a closure theory to predict the evolution of density fluctuations and the associated cross-field transport driven by Alfvénic motions. The results suggest that wave-driven cross-field transport may contribute to the long-term density evolution of coronal loops, implying that loop plasma may be less isolated than commonly assumed.

Investigating spatio-temporal evolution of active region AR12740 using overlappogram inversion in Hinode/EIS slot data

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Poster

Determining the mechanisms and frequency of coronal heating remains a longstanding challenge in solar physics. Extreme Ultraviolet (EUV) spectroscopy offers critical diagnostics to address these questions. For decades, slit EUV spectroscopy has been used to determine plasma parameters such as temperature, density, velocity, and elemental abundance using 1" and 2" slit observations from Hinode/EIS. Spatial imaging is carried out via a rastering process, which significantly limits co-temporal spatial-spectral information. As a result, short-term variations in coronal parameters are lost.

Slot spectroscopy preserves co-temporal information over a much larger spatial region, but the spatial and spectral information overlap, producing what is known as spectroheliograms (also known as overlappograms). An overlappogram inversion technique has recently been shown to recover spectrally pure images from Hinode/EIS slot observations. In this work, we apply this technique to Hinode/EIS 266" slot observations to investigate short-term (within 1-hour) and long-term (3-day) temporal and spatial evolution of active region AR12740 across multiple emission lines between May 7, 2019, and May 9, 2019.

Modelling Torsional Alfvén Waves in Coronal Waveguides

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Poster

Torsional Alfvén waves are a promising mechanism for transporting energy through the solar atmosphere, with implications for coronal heating and solar wind acceleration. Recently, signatures of torsional Alfvén waves have been observed with DKIST. We aim to investigate the effects of line-of-sight integration and plasma conditions on the observable properties of the torsional mode. We present 3D MHD simulations of multiple coronal waveguides, driven by a combination of transverse and torsional wave drivers, considering two plasma regimes representative of active region (AR) and quiet Sun (QS) conditions. Synthetic observables of the Fe XIII 1074.7 nm coronal emission line are produced using the pyCELP forward-modelling framework to enable direct comparison with spectroscopic observations. In the QS regime, red-blue Doppler asymmetries are associated with the driven torsional waves, though their observed amplitudes are substantially reduced by line-of-sight integration. In contrast, the AR regime exhibits red-blue Doppler asymmetries even in the absence of an imposed torsional driver, which may be misidentified as the m=0 torsional Alfvén mode. In the AR setup, the red-blue Doppler asymmetries arise from strong phase mixing, generating shear flows and localised vorticity between waveguides where emission is strongest. The differences between the two regimes are governed by the location of peak emission, which is determined by the degree of density inhomogeneity. Our results support the identification of torsional Alfvén wave signatures in weakly inhomogeneous environments (e.g. quiet Sun), but caution should be taken when interpreting spectroscopic observations in strongly inhomogeneous environments such as active regions.

Deriving Coronal Heating Scaling Laws from 3D MHD Simulations

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Oral

Determining how coronal heating depends on magnetic field strength (B) and loop length (L) is crucial for constraining the physical processes responsible for heating the solar corona. We perform a parameter study using 3D MHD simulations of a subset of an active region to investigate the dependence of the coronal heating rate on B and L. The simulations model the formation of nanoflares driven by photospheric motions and include optically thin radiative losses and field-aligned thermal conduction to capture the thermodynamic response of the plasma. By varying the magnetic field strength and loop length, we quantify the dependence of the time-averaged volumetric heating rate (Q) and derive a scaling law of the form $Q \propto B^a L^b$. The results show a strong direct dependence of the heating rate on magnetic field strength and an inverse dependence on loop length. The obtained scaling exponents fall within the range expected from coronal heating scenarios in which energy dissipation occurs either when tangled and twisted magnetic strands exceed a critical misalignment angle or when current sheets lose equilibrium and become unstable. The results offer constraints for theoretical models of coronal heating and can be incorporated into other models (e.g., active region or global corona) that rely on parameterized heating prescriptions.

Multi-wavelength response of the photosphere, chromosphere and corona to a C-class flare on 1 July 2012

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Oral

A multi-instrument study of a C-class flare on 1 July 2012 is presented, investigating the coupled photosphere, chromosphere, and corona before, during, and after the event. The analysis combines high-resolution Swedish Solar Telescope observations, including H-alpha and photospheric diagnostics, with Solar Dynamics Observatory data. Particular attention is given to the response observed in multiple AIA channels in order to trace the coronal and transition-region evolution associated with the flare. To quantify magnetic restructuring, the spatial and temporal evolution of electric current densities before and after the flare is examined using vector magnetic field information, allowing an assessment of how the photospheric field responds to impulsive energy release. Magnetic connectivity is further investigated through potential field extrapolations using HMI data. These extrapolations are compared with flare ribbon evolution and coronal loop responses identified in the imaging data. The aim is to relate changes in lower-atmosphere magnetic structure, current density, and flare ribbon morphology to the coronal loop system involved in the event. The study provides a detailed case study of how a modest flare reorganises magnetic connectivity across multiple atmospheric layers and demonstrates the value of combining high-resolution ground-based observations with space-based coronal diagnostics.

Spatially Coherent and Intermittent Alfvénic Fluctuations in Doppler Velocity of Polar Spicules from IRIS Observations

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Poster

Alfvénic fluctuations are widely considered a key mechanism for transporting energy from the lower solar atmosphere into the corona, with spicules acting as dynamic conduits for this transfer. We investigate transverse and Doppler velocity fluctuations in tall, quiet-Sun polar spicules observed in the Si IV 1394 Å line by the Interface Region Imaging Spectrograph. Fourier analysis performed in both time and space enables a unified characterization of the frequency and spatial scale distribution of wave power. Temporal power spectra reveal broadband fluctuations extending to 10 mHz with power-law behavior and enhanced power in the 3–5 mHz range, consistent with outwardly propagating Alfvénic motions. Spatial Fourier analysis of Doppler velocity fluctuations demonstrates scale-dependent structure indicative of energy transfer across spatial scales. To assess the statistical nature of these fluctuations, we compute velocity increment probability distribution functions and kurtosis, revealing signatures of intermittency and departures from Gaussian statistics. The spatial coherence of transverse motions is further quantified through cross-correlation of neighboring Doppler velocity signals, providing direct observational estimates of correlation length scales relevant to models of Alfvén wave turbulence. These results provide new observational constraints on the spatial organization, coherence, and turbulent evolution of Alfvénic fluctuations in spicules, offering insight into their role in mediating chromosphere–corona energy coupling.

Non-Gaussian line profiles in IRIS full-disk Si IV observations, and where to find them

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Oral

Spectral observations of the transition region emission in the solar corona with the Interface Region Imaging Spectrograph (IRIS) at high spatial and spectral resolution reveal that a non-negligible portion of these line profiles are non-Gaussian (e.g., Dudik et al. 2017, Ayres et al. 2021). The presence of non-Gaussian profiles at the fine spatial resolution of IRIS provides constraints on the possible origin of such line profiles (e.g., k-distribution), and on the spatial properties of such phenomena. Here we present a follow-up of the study of IRIS full-disk mosaics by Ayres et al. (2021). We focus on the strong transition region Si IV 1393A line, and we investigate in further detail the relation between solar features and the transition region spectral profiles, through the use of SDO and Hinode observations coordinated with these IRIS datasets.

Coronal Loops are not Projected Veils

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Oral

We conduct an in-depth investigation of the projection effects involved in the observations and interpretation of coronal loops in the optically thin corona. An extended set of statistical signatures is used to characterize the line-of-sight (LOS) integrated emission signals obtained from numerical models implementing a wide range of different projection geometries, as well as the loop profiles observed by the extreme ultraviolet telescope on board the flight 2.1 of the High-Resolution Coronal Imager (Hi-C). The results obtained indicate that typical cross-sectional emission envelopes of the Hi-C loops are unlikely to have high eccentricity. They are also inconsistent with the "coronal veil" scenario which attempts to explain the observed loops as accidental LOS alignments of a complex quasi-two-dimensional emitting structure. Our findings strongly suggest that the majority of the observed loops are true quasi-one-dimensional (roughly axisymmetric) structures embedded into the three-dimensional coronal volume, therefore ruling out the veil-based interpretation.

MAD damping of slow waves as a seismological tool for probing the multi-thermal structure of coronal loops

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Slow waves in solar coronal loops are strongly damped. The current theory of damping by thermal conduction cannot explain some observational features. We investigate the propagation of slow waves in a coronal loop built up from strands of different temperatures. We consider the loop to have a multithermal, Gaussian temperature distribution. The different propagation speeds in different strands lead to a multithermal apparent damping (MAD) of the wave, similar to observational phase mixing. We use an analytical model to predict the damping length and propagation speed for the slow waves, including in imaging with filter telescopes such as SDO/AIA. We have found how the filter response function changes the observed wave propagation speed and damping, and we have checked this by comparison to forward models of numerical simulations. Using this new theory for matching multi-filter observations of slow waves, allows us to probe the thermal structure of the loop independently from the more traditional DEM method.

Compression, Impact and Hot Rebound Flows from Coronal Rain Downflows

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Oral

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 ≈600 km and densities of ≈6 $\times 10^{11}$ 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 levels (4.64 $\times 10^{26}$ erg), with clumps producing impacts that reach the lower transition region and are visible across all EUV channels and in SJI 1400 Å. 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 the heating driving TNE-TI cycles.