9th Coronal Loops Workshop
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University of St Andrews

Abstract Booklet

Sponsors

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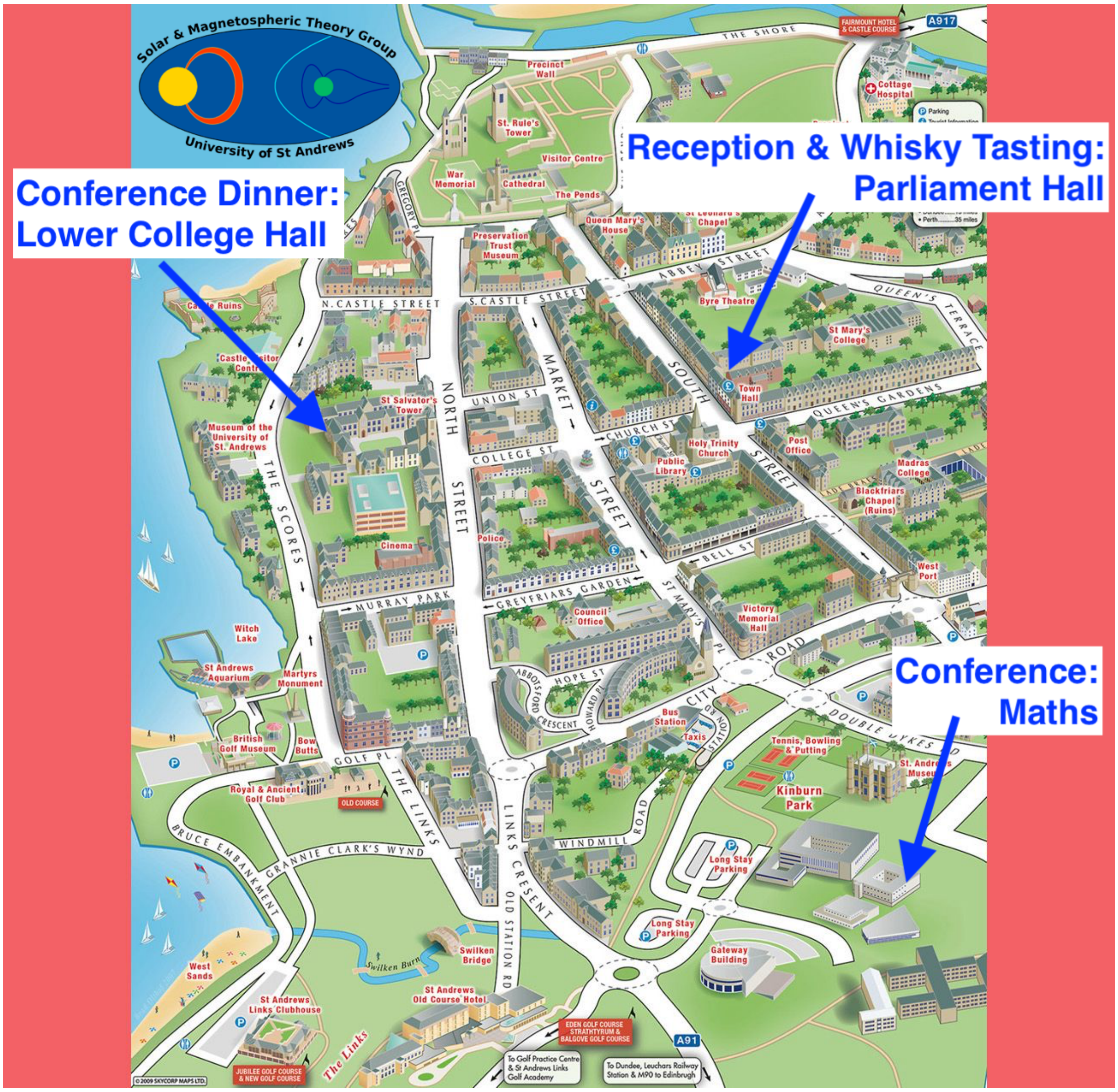
Map



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Abstracts

Talks: Session 1: Tuesday - 09:00

AC/DC - is it really relevant? (Invited)

Boris Gudiksen (RoCS)

The improvement in observations and numerical tools to understand the solar corona, has for the last number of years confused the traditional AC/DC split of heating theories and produced a muddy picture. The AC picture traditionally meant dissipation of waves transmitted through the solar atmosphere, while the DC picture meant reconnection of magnetic field both producing heat at their dissipation locations. Even though the details of wave dissipation and the details of reconnection have been the subject of very complicated analytical and numerical experiments, maybe we are missing a crucial point.Since AC and DC really describes the "engine" that drives the energy transport, we seem to be no closer to agreeing on a dissipation mechanisms. One reason might be that the dissipation mechanism we personally favour is complicated. The dissipation of waves in the solar corona is complicated, just as the details of fast reconnection. But it is not just complicated to investigated from an observational viewpoint - getting a model to agree with the observations seem even more complicated. More and more observational evidence points towards a complicated picture - one which we will have to incorporate into our models, both numerical and analytical, investigative and full blown, in order for us to understand the solar atmosphere.

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Talks: Session 1: Tuesday - 09:30

Exploring Active Region Heating Using a 3D, Volume-Filling Model of the Solar Corona

Cooper Downs (Predictive Science Inc.)

Cooper Downs (Predictive Science Inc.), Zoran Mikić (Predictive Science Inc.), Roberto Lionello (Predictive Science Inc.), Amy R. Winebarger (NASA Marshall Space Flight Center), James A. Klimchuk (NASA Goddard Space Flight Center)

We discuss our recent efforts to test coronal heating models using a 3D, volume-filling model of the solar corona. Our approach modifies a thermodynamic MHD model of the global corona to solve only for the field-aligned, parallel hydrodynamic evolution of the plasma. This enables an efficient framework with which to study coronal heating for realistic, low-beta magnetic field configurations. The 3D, volume-filling nature of the calculation enables runs that sample a large-parameter space in loop properties, and provide full line-of-sight (LOS) information for calculating forward modeled observables. We use this approach to test multiple coronal heating models for NOAA active region 11339, including empirical heating models with stratified heating, and a wave-turbulence-driven (WTD) heating model based on the dissipation of Alfveén waves. We synthesize key observables for each model and discuss them in the context of coronal heating signatures, including differential emission measure (DEM) distributions and time-lags between emission bandpasses. Of particular interest are the rich time-dependent signatures that arise out of relatively steady but stratified heating parametrizations.

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Talks: Session 1: Tuesday - 09:45

A Fast and Accurate Method to Capture the Solar Corona/Transition Region Enthalpy Exchange

Craig Johnston (University of St Andrews)
C. D. Johnston (University of St Andrews) & S. J. Bradshaw (Rice University)

The brightness of the emission from coronal loops in the solar atmosphere is strongly dependent on the temperature and density of the confined plasma. After a release of energy, these loops undergo a heating and upflow phase, followed by a cooling and downflow cycle. Throughout, there are significant variations in the properties of the coronal plasma. In particular, the increased coronal temperature leads to an excess downward heat flux that the transition region is unable to radiate. This generates an enthalpy flux from the transition region to the corona, increasing the coronal density. The enthalpy exchange is highly sensitive to the transition region resolution in numerical simulations. With a numerically under-resolved transition region, major errors occur in simulating the coronal density evolution and, thus, the predicted loop emission. We present a new method that addresses the difficulty of obtaining the correct interaction between the corona and corona/chromosphere interface. In the transition region, an adaptive thermal conduction approach is used that broadens any unresolved parts of the atmosphere. We show that this approach, referred to as TRAC, successfully removes the influence of numerical resolution on the coronal density response to heating while maintaining high levels of agreement with fully resolved models. When employed with coarse spatial resolutions, typically achieved in multi-dimensional MHD codes, the peak density errors are less than 3% and the computation time is three orders of magnitude faster than fully resolved field-aligned models.

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Talks: Session 1: Tuesday - 10:00

Hot and cool loops in active region cores running in parallel

Hardi Peter (Max Planck Institute for Solar System Research)
H. Peter (MPS), L.P. Chitta (MPS), J. Warnecke (MPS), F. Chen (LASP) & Hi-C team

Combining observations of plasma in active region cores at 1 MK and 0.1 MK we find that the loops seen at these very different temperatures are nicely aligned and run in parallel with a small spatial offset. This gives new insight into the magnetic structuring and in particular into the presence of fieldline braiding to energise these loops. For our observations we use data from the second Hi-C rocket experiment launched in 2018 that provides the highest resolution data ever taken of plasma at 1 MK and combine this with data from IRIS, roughly matching in spatial resolution. Using a careful alignment between IRIS and Hi-C we find that the cool and warm loops are not exactly co-spatial. The loops at 0.1 MK and 1 MK do not simply show plasma at different evolution (cooling) stages. Instead, they are decoupled thermally and evolve independently.We compare these observations to 3D MHD models of a coronal active region. We will demonstrate that such a 3D model can recover key features of an active region structure, and that emerging loops in the core of an active region show features similar to the co-spatial Hi-C and IRIS loops. In the numerical experiments we have full access to the state of the plasma and the magnetic field. From these we conclude that the cool (0.1 MK) loops are originating from the tip of the chromosphere that is found just below low-lying warm (1 MK) coronal loops that have emerged into the upper atmosphere. Depending on the line-of-sight, the hot and cool structures might appear to be co-spatial, but in general will have a (small) spatial offset, just as in the observations. This also sheds new light on the long-standing question of a multi-thermal versus single-temperature structure of coronal loops. The Hi-C and IRIS observations together with the 3D MHD modelling show how these cool and hot active region loops form and how they are heated through flux-tube-tectonics, a variant of fieldline braiding.

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Talks: Session 1: Tuesday - 11:15

A coronal loop in a box: comparing the role of fieldline braiding and flux cancellation in a model from below the solar surface to the corona

Cosima Breu (Max Planck Institute for Solar System Research)
H. Peter (MPS), R. Cameron (MPS), S.K. Solanki (MPS), D. Przybylski (MPS), L. P. Chitta (MPS)

In order to distinguish the contribution of different heating processes such as field line braiding, waves, and flux cancellation, we run 3D numerical experiments of an isolated coronal loop. We follow the well-established concept of a loop in a rectangular box, and extend the concept to include the near surface convection that self-consistently produces the changing magnetic structures as found in the photosphere of a loop footpoint in a plage region. The high resolution of our models allows us to resolve the magnetic roots of the loop in the inter-granular magnetic field concentrations and the turbulent evolution of the magnetic field in the coronal part of the loop.The loop is modelled as an initially straight magnetic flux tube rooted in two photospheric layers above a shallow convection zone at the top and bottom boundary of the rectangular simulation box. The computational domain spans from the upper part of the convection zone into the corona, going well beyond existing models for straightened loops. Using the MURaM code, we have a realistic description of the convection zone and photosphere, including radiative transfer, and at the same time have heat conduction and optically thin radiative losses included, which is essential in the coronal part. The magnetic field at the photospheric levels resembles a plage region. Instead of being prescribed at the boundaries, the driving of each loop footpoint arises self-consistently from magnetoconvection.The driving at the footpoints leads to a braided turbulent state of the magnetic field with complex patterns as found in models of straightened loops before. Having a self-consistent photosphere at the base of the loop we can now clearly relate transient enhancements of the heat input to motions and changes of the magnetic flux tubes rooted in the photosphere. In response to these heating events, loop strands form in coronal emission synthesized from the model. In addition to the braiding of the magnetic field, we also see small opposite magnetic field patches being created by the magnetoconvection. When these flux patches cancel, the associated reconnection deposits energy at the loop base. Our aim for the immediate future is to compare the role played by flux cancellation of elements of opposite magnetic polarity near the footpoints for the injection of energy into coronal loops to field line braiding and waves.

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Talks: Session 1: Tuesday - 11:30

The Role of Magnetic Helicity in Coronal Heating

Spiro Antiochos (NASA/GSFC)

K. J. Knizhnik (NRL), C. R. DeVore (GSFC), J. A. Klimchuk (GSFC)

One of the greatest challenges in solar physics is understanding the nature of the heating of the Sun's multi-million degree corona. Many theories for coronal heating postulate that free energy in the form of magnetic twist/stress is injected by the photosphere into the corona where the free energy is converted into heat either through reconnection or wave dissipation. The magnetic helicity associated with the twist/stress, however, is expected to be conserved and, therefore, manifest itself in the corona; but, observations of coronal loops invariably reveal smooth, laminar structures with negligible twist or tangling. In previous work, we showed that this lack of complexity buildup in coronal loops can be explained by the inverse cascade of helicity via magnetic reconnection. The small-scale magnetic stress ends up as the observed large-scale shear of filament channels. We now demonstrate, using helicity and energy conserving numerical simulations of a coronal system driven by photospheric motions, that the "helicity condensation" process provides a natural mechanism for heating the solar corona. We show that the heat generated by the magnetic reconnections responsible for the helicity condensation produces sufficient energy to account for the observed coronal heating. We study the role that helicity injection plays in determining coronal heating and find that, crucially, the heating rate is largely independent of the rate of helicity injected by the photospheric driving motions. This work was supported by the NASA Living With A Star Program.

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Talks: Session 1: Tuesday - 11:45

Using Coordinated Observations from the Flight of the High Resolution Coronal Imager to Constrain Active Region Heating Scenarios

Harry Warren (NRL)

Harry Warren, Jeffrey Reep, Ignacio Ugarte-Urra, and Nicholas Crump (NRL) and the Hi-C Science Team

Excellent coordinated observations of active region 12712 were obtained from EIS, XRT, IRIS, AIA, and HMI during the second flight of the High Resolution Coronal Imager (Hi-C) sounding rocket on May 29, 2018. This region displayed a typical active region core structure with relatively short, high temperature loops crossing the polarity inversion line and bright moss located at the footpoints of these loops. The differential emission measure computed from EIS, AIA, and XRT is very sharply peaked at ∼4 MK. Further, there is little evidence for impulsive heating in the moss, even at the resolution and cadence of Hi-C. This suggests that active region core heating is occurring at relatively high-frequency. To create a time-dependent simulation of the active region core, we combine non-linear force-free extrapolations of the photospheric magnetic field measured by HMI with a heating rate that is dependent on the field strength and loop length and has a Poisson waiting time distribution. To model the coronal emission we use (0D) EBTEL calculations. To model transition region and chromospheric dynamics in selected moss regions we use the full hydrodynamics, including radiative transfer, from HYDRAD. We find that the observations are generally consistent with a high-frequency heating scenario. In this talk we also briefly review the ability of non-linear force-free extrapolations to reproduce the topology of the corona and the observed relationship between the radiative signatures of transient brightenings and the magnetic properties of the corresponding coronal loops.

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Talks: Session 1: Tuesday - 12:00

Studying Coronal Heating with Data Driven Active Region Modeling using GX Simulator

Samuel Schonfeld (NASA / USRA)
Jim Klimchuk (NASA)

Recent upgrades to the GX Simulator data-driven active region modeling IDL tool integrating the EBTEL (Enthalpy-Based Thermal Evolution of Loops) coronal loop model allow for detailed analysis of the impact of coronal heating parameterization on coronal emission. We test this new capability using a unique set of simultaneous observations of active region NOAA 11809 in the X-ray, extreme ultraviolet (EUV), and microwave collected with Hinode, the Solar Dynamics Observatory, and the Very Large Array (VLA). Photospheric magnetic field measurements are extrapolated into the corona using NLFFF (non-linear force-free field) techniques and then coronal plasma is populated using EBTEL models run assuming various coronal heating prescriptions. Emission from the active region is then simulated and compared to the many available observations. We present initial results comparing multiple heating parameterizations and discuss the implications of these findings on the nature of coronal heating properties.

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Talks: Session 2: Tuesday - 14:00

Combining Active Region Observations and Models to Confront Coronal Heating Theories (Invited)

Amy Winebarger (NASA MSFC)

Coronal heating remains a "hotly" debated topic in solar astrophysics. Quiescent active regions provide an interesting laboratory to study coronal heating. The magnetic field in active regions is strong enough to be measured by reliably measured modern line-of-sight and vector magnetograms and the hot coronal plasma is dense enough to be imaged by narrow and broad band imagers and sampled by spectrometers at a relatively high resolution and fast cadence. This has provided the necessary data and constraints to develop and test 0D to 3D models. In this talk, I will review the current state of available active region observations and models and how the two compare. Additionally, I will highlight future upcoming observations and model developments.

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Talks: Session 2: Tuesday - 14:30

NuSTAR observations of the quietest Sun

Iain Hannah (University of Glasgow)

Cooper (Glasgow), Grefenstette (Caltech), Glesener (UMN), Krucker (UCB/FHNW), Smith (UCSC), Hudson (UCB/Glasgow), White (AFRL), Kuhar (FHNW)

Observing X-rays (above a few keV) from the Sun provides a direct insight into energy release (heating and/or particle acceleration) in the solar atmosphere. Targeting the faintest X-ray emission allows the study of the smallest solar flares/brightenings, and their contribution to heating coronal loops. NuSTAR is an astrophysics telescope that uses directly focusing X-rays optics to detect weak X-rays from the Sun. We have observed the Sun many times since the start of solar pointings in Sep 2014 through to our latest observations in 2019. See http://ianan.github.io/nsovr/ for an overview. During the current solar minimum, NuSTAR has observed X-rays from a variety of sources when the Sun is devoid of active regions, during periods of the very quietest conditions. The NuSTAR X-ray images of these weak sources are related to features seen at lower energies, such as in softer X-rays with Hinode/XRT and EUV with SDO/AIA. Crucially, NuSTAR's imaging spectroscopy allows us to obtain and fit the X-ray spectrum from these small events determining the properties. We will present some of the latest solar observations with NuSTAR as we go through the current solar minimum.

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Talks: Session 2: Tuesday - 14:45

Magnetic transients at coronal loop footpoints in a solar plage

Lakshmi Pradeep Chitta (Max Planck Institute for Solar System Research)
A. R. C. Sukarmadji (University of St Andrews; Max Planck Institute for Solar System Research), L. Rouppe van der Voort (Rosseland Centre for Solar Physics, University of Oslo; Institute of Theoretical Astrophysics, University of Oslo), H. Peter (Max Plan

Solar plages are patches of mostly unidirectional magnetic field extending several arcsec on the photosphere. Densely packed coronal loops are often observed to be rooted in these plages. The evolution and energetics of plage magnetic field will play a key role in heating the overlying loops. We will present results from the high-resolution magnetic field observations of a plage obtained from the Swedish 1-m Solar Telescope (SST). These observations reveal granular-scale transient events of flux emergence and cancellation in the apparent unipolar magnetic region. These transient events occur at the footpoints of coronal loops observed with the Solar Dynamics Observatory. The coronal response to magnetic transients is observed, which suggests an important role of such events in the heating of the overlying loops.To estimate the energetics associated with magnetic transients, we performed high-resolution MHD simulations of magnetoconvection in a typical plage region with unipolar magnetic field as the initial condition. The magnetoconvection self-consistently drives granular-scale flux emergence and cancellation events similar to those found in the SST observations. Individual events transfer an energy flux in excess of 1 MW m-2 through the photosphere which can be fed into the corona through reconnection.Our observations and simulations highlight the complex evolution of magnetic field and transients in unipolar plages. We will discuss their role in the heating of coronal loops.

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Talks: Session 2: Tuesday - 15:00

Diagnosing Coronal Heating with the Time-lag method Applied to Spectroscopy

Nicholeen Viall (NASA/GSFC)
James Klimchuk (NASA/GSFC), Phillip Chamberlin (U. of Colorado/LASP), and Jeffrey Brosius (NASA/GSFC and The Catholic University of America)

We investigate the properties of coronal heating using a systematic analysis of EUV light curves called the time-lag method. It is an automated method to detect heating and cooling cycles in the solar corona by measuring how the evolution of emission formed at one temperature correlates with the evolution of emission formed at other temperatures. We have applied it to light curves of active regions on a pixel-by-pixel basis using data taken with the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) and identified the well-known cooling loops, as well as cooling patterns in the diffuse emission between loops. AIA has excellent spatial resolution, but lacks temperature fidelity. Here we apply the time-lag method to light curves in spectral lines, which provide a better measure of temperature. We apply it to SDO Extreme Ultraviolet Variability Experiment (EVE), disk integrated observations and to sit-and-stare observations of an active region made by Hinode's EUV Imaging Spectrometer (EIS). In both cases, we identify a time-lag, or time-lags, consistent with those previously found in active regions. We discuss the observational trade-space of spatial resolution, spatial coverage, and temperature resolution in the context of observing heating and cooling cycles with the time-lag method. Lastly, the success of the method applied to the disk-integrated observations demonstrates possible applications to stellar observations.

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Talks: Session 2: Tuesday - 16:15

Impulsive Heating of Coronal Loops from Large-Scale Magnetic Rearrangements

Fabio Reale (Universita di Palermo)
Paola Testa (Center for Astrophysics Harvard & Smithsonian, USA), Antonino Petralia (INAF-Osservatorio Astronomico di Palermo, Italy), David R. Graham (NASA, USA)

The Interface Region Imaging Spectrograph (IRIS) has observed bright spots at the transition region footpoints associated with heating in the overlying loops, as observed by coronal imagers. Some of these brightenings show significant blueshifts in the Si IV line at 1402.77 A (T$\sim 10^4$.9 K, Testa et al. 2014). Such blueshifts could not be reproduced by coronal loop models assuming heating by thermal conduction only, but are consistent with electron beam heating, highlighting for the first time the possible importance of non-thermal electrons in the heating of non-flaring active regions (Testa et al. 2014, Polito et al. 2018). Here we report on the coronal counterparts of these brightenings observed in the hot channels of the Imaging Atmospheric Assembly on board the Solar Dynamics Observatory. We show that the IRIS bright spots are the footpoints of very hot and transient coronal loops which clearly experience strong magnetic interaction and rearrangements, thus confirming the impulsive nature of the heating and providing important constraints for physical interpretation. We also show the detection of pulsations along the brightening loops in a hot EUV channel of SDO/AIA.

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Talks: Session 2: Tuesday - 16:30

Impulsive coronal heating from large-scale magnetic rearrangements: MHD modeling

Antonino Petralia (INAF/Osservatorio Astronomico di Palermo)
F. Reale (Universitá di Palermo, Italy), P. Testa (Smithsonian Astrophysical Observatory, USA)

IRIS has observed bright spots at the transition region footpoints. These spots showed significant blueshifts in the Si IV line at 1402.77A (T=$10^{4.9}$K). Such blueshifts could not be reproduced by coronal loop models assuming heating by thermal conduction only, but were consistent with electron beam heating, highlighting for the first time the possible importance of non-thermal electrons in the heating of non-flaring active regions (Testa et al. 2014, Polito et al. 2018). The coronal counterparts of these brightenings observed in the hot channels of the Imaging Atmospheric Assembly on board the Solar Dynamics Observatory show that the IRIS bright spots are the footpoints of very hot and transient coronal loops which clearly experience strong magnetic rearrangements (Reale et al., this meeting). Here we explore in detail how these hot loops might be produced through numerical 3D MHD modeling of interacting magnetic structures including the full plasma chromospheric and coronal response.

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Talks: Session 3: Wednesday - 09:00

Forward Modeling and Machine Learning as Tools for Making Meaningful Comparisons Between Observations and Simulations (Invited)

Will Barnes (Lockheed Martin Solar and Astrophysics Laboratory / Bay Area Environmental Research Institute)
Stephen Bradshaw (Rice University), Nicholeen Viall (NASA Goddard Space Flight Center)

Any successful model of coronal heating in non-flaring active region core loops must be able to reproduce the full range of observational signatures. These signatures, or observables, include, but are not limited to, the slope of the emission measure distribution below the peak temperature in log-log space, the time delay which maximizes the cross-correlation between narrow-band intensities, and the presence of "very hot" ($>$ 8 MK) plasma. Quantitatively assessing agreement between models and observations in the context of these observables is critical to constraining the parameter space of possible coronal heating mechanisms. In this talk, I will discuss the importance of forward modeling and machine learning in making meaningful comparisons between observations and simulations. In particular, I will highlight the results of a recent investigation into the frequency of energy deposition in active region NOAA 11158 and discuss how machine learning, specifically random forest classification, is used to assess agreement between observations and forward models of low-, intermediate-, and high-frequency heating.

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Talks: Session 3: Wednesday - 09:30

Study of Type III Radio Bursts in Nanoflares

Sherry Chhabra (New Jersey Institute of Technology/NASA GSFC)
James A. Klimchuk (NASA GSFC), Nicholeen M. Viall (NASA GSFC),
Dale E. Gary (New Jersey Institute of Technology)

The heating mechanisms responsible for the million-degree solar corona remain one of the most intriguing problems in space science. It is widely agreed, that the ubiquitous presence of reconnection events and the associated impulsive heating (nanoflares) are a strong candidate in solving this problem [Klimchuk J.A., 2015 and references therein].Whether nanoflares accelerate energetic particles like full-sized flares is unknown. The lack of strong emission in hard X-rays suggests that the quantity of highly energetic particles is small. There could, however, be large numbers of mildly energetic particles ($\sim$ 10 keV). We investigate such particles by searching for the type III radio bursts that they may produce. If energetic electron beams propagating along magnetic field lines generate a bump-on-tail instability, they will produce Langmuir waves, which can then interact with other particles and waves to give rise to emission at the local plasma frequency and its first harmonic. Type III bursts are characteristically known to exhibit high frequency drifts as the beam propagates through a density gradient. The time-lag technique that was developed to study subtle delays in light curves from different EUV channels [Viall & Klimchuk 2012] can also be used to detect subtle delays at different radio frequencies. We have modeled the expected radio emission from nanoflares, which we used to test and calibrate the technique. We have begun applying the technique to actual radio observations from VLA (Very Large Array) and seeking data from MWA (Murchison Widefield Array) as well. Our goal is to determine whether nanoflares accelerate energetic particles and to determine their properties. The results will have important implications for both the particle acceleration and reconnection physics.

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Talks: Session 3: Wednesday - 09:45

Heating coronal loops by nanoflares: testing Klimchuk's hypothesis

Stephane Regnier (Northumbria University)

Parker's nanoflare model (1988) is widely used to describe the heating of the corona localised along magnetic loops. However, the model is viable only if the number of events is large and covers the whole solar sphere. Klimchuk (2015) argued that more than 100,000 current sheets should exist in an active region to produce a sufficient heating of the corona up to 1 MK. In order to validate Klimchuk's model, we study the dynamics of a quiet-Sun region observed by Hinode/SOT. From a potential field model, we derive the existence of tangential discontinuities, signatures of current sheets. We obtain that, at a given time, there exists a large number of tangential discontinuities that have potentially a free energy of pico- to nano-flare energies. The current sheets are located in the photosphere and chromosphere, but just a small number of current sheet is located in the corona where the topology of the magnetic field is less tangled/twisted. The density of current sheets is constant in time. This analysis supports Klimchuk's argument regarding Parker's model, and also predicts energy releases at the picoflare scale.

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Talks: Session 3: Wednesday - 10:00

CORONAS-F/SPIRIT Mg XII and Nanoflares

Anton Reva (Lebedev Physical Institute)
Artem Ulyanov, Alexey Kirichenko, Sergey Bogachev, Sergey Kuzin

Nanoflare-heating theory predicts steady hot-plasma emission in non-flaring active regions. It is hard to find this emission with conventional non-monochromatic imagers (such as AIA or XRT), because their images contain a cool-temperature background. In this work, we search for hot plasma in non-flaring active regions using the Mg XII spectroheliograph onboard the CORONAS-F/SPIRIT. This instrument acquired monochromatic images of the solar corona in the Mg XII 8.42 O line, which emits only at temperatures higher than 4 MK. The Mg XII images only contain the signal from hot plasma, without any low-temperature background. We studied the hot plasma in active regions using SPIRIT data from 18-28 February 2002. During this period, the Mg XII spectroheliograph worked with a 105-second cadence almost without data gaps. Hot plasma was observed only in the flaring active regions. We did not observe any hot plasma in non-flaring active regions. The hot-plasma column emission measure in the non-flaring active region is not expected to exceed $3 \times 10^{2}4$ cm^{-5}. The hot differential emission measure is lower than 0.01% of the DEM of the main temperature component. The absence of Mg XII emission in the non-flaring active regions can be explained by weak and frequent nanoflares (with a delay of less than 500 seconds) or by very short and intense nanoflares that lead to non-equilibrium ionization.

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Talks: Session 3: Wednesday - 11:15

Is Hi-C Resolving Coronal Strands? Results from AR12712

Thomas Williams (UCLAN)
T. Williams (UCLAN), R.W. Walsh (UCLAN), A. Winebarger (NASA Marshall Space Flight Center), & the Hi-C team

The High-resolution Coronal Imager (Hi-C) has been launched three times from White Sands Missile Range. The first launch (Hi-C 1), occurred on 11 July 2012 and during the 345 seconds of data acquisition, Hi-C 1 obtained the highest spatial resolution and highest cadence images of the EUV (19.3 nm) solar corona ever achieved. Those few minutes of data have thus far generated >25 refereed publications and is arguably one of the most scientifically successful sounding rocket payloads ever launched by NASA. Unfortunately, the second launch (Hi-C 2) did not result in any science data.On 29 May 2018, it was launched for a third time (Hi-C 2.1). On this occasion, 329 seconds of 17.2 nm data of target active region (AR12712) was captured with a cadence of $\sim$ 5.5s, and a plate scale of $\sim 0.13 \times 0.13$ arcsec^2/pixel.Here we outline investigations of coronal strands as seen from Hi-C 2.1 and SDO/AIA 17.1 nm observations. We search for evidence of substructure within the strands which is not detected by AIA, and whether they are fully resolved by Hi-C 2.1. With the aid of Multi-Scale Gaussian Normalisation (MGN), strands from a region of low-emission which can only be visualised against the contrast of the darker, underlying moss are studied. A comparison is made between these low-emission strands with those from regions of higher emission within the target active region. It is found that we can resolve individual strands as small as $\sim$215 km, though more typical strands width seen are $\sim$500 km, placing them beneath the resolving capabilities of SDO/AIA.

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Talks: Session 3: Wednesday - 11:30

Reconnection microjets in solar coronal loops

Patrick Antolin (University of St Andrews)
Paolo Pagano (University of St Andrews), Ineke De Moortel (University of St Andrews), Paola Testa (Harvard-Smithsonian Center for Astrophysics), Antonino Petralia (INAF-Osservatorio Astronomico di Palermo), Fabio Reale (INAF-Osservatorio Astronomico di Pa

Coordinated observations with SDO/AIA, IRIS and Hinode/SOT were combined to reveal unique signatures of magnetic reconnection at high resolution leading to coronal heating of a loop structure. The loop is initially subject to thermal instability leading to the appearance of coronal rain that allows the dynamic tracing of the coronal magnetic field during the reconnection process and heating to multi-million degree temperatures. Single and clustered reconnection events can be distinguished and are characterised by a strong transverse displacement of an internal loop strand, a localised intensity burst in the strand and, in particular, the presence of a microjet a fast (200 km/s), bursty, very short lived (on the order of 10 s) and small-scale (500 km width, 1500 km in length) jet-like structure stemming from the rain strand and perpendicular to it. The strongest events are accompanied by the ejection of small-scale plasmoids along the jet axis. The main characteristics of a microjet are recovered by 3D MHD modelling of magnetic reconnection between slightly misaligned coronal loop structures. Furthermore, the observed spatial and temporal evolution of the reconnection events show characteristics of an MHD avalanche: the events are first clustered and highly localised near the loop apex. They expand within minutes across and along the loop. Internal rotational motions and an increase in the overall loop intensity accompany the entire process. The telltale observational signatures of the events allow a clear distinction of heating mechanisms based on magnetic reconnection, thereby providing the perfect target for next-generation high-resolution instruments to disentangle between heating mechanisms.

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Talks: Session 3: Wednesday - 11:45

Propagating disturbances in coronal loops

Krzysztof Barczynski (LESIA, Observatoire de Paris, Universite PSL, Sorbonne Universite, Meudon)

Krzysztof Barczynski (1;2), Hardi Peter (2), Lakshmi Pradeep Chitta (2): (1) LESIA, Observatoire de Paris, Université PSL, Sorbonne Université, Meudon, France; (2) Max-Planck-Institute for Solar System Research in Göttingen, Germany.

The origin of propagating disturbances observed as small-scale brightenings moving along a coronal loop is still an open issue. To address this, we study observations of disturbances in a coronal loop propagating from the temperature-minimum region into the corona and relate this to the underlying photospheric magnetic field. These observations suggest that the magnetic field evolution plays an essential role in generating the observed disturbances. To investigate the evolution of the propagating disturbance and their relation to the underlying magnetic field, we use imaging diagnostics of the solar atmosphere (IRIS,SDO/AIA) and photospheric magnetic field maps (HINODE, SDO/HMI).We find a time delay in the intensity maxima of propagating disturbances that increase from the temperature minimum through the chromosphere into the corona. The propagating disturbance shows a clear quasi-periodicity of about 10 min. In the highly inclined loop, the apparent speeds of propagating disturbances increase from the transition region ($\sim$20km/s) to the corona ($\sim$70km/s), suggesting that these disturbances are subsonic. Our preliminary results show that the evolution of small-scale magnetic field concentrations at the base of the loop is tightly connected to the generation of propagating disturbance.We suggest that propagating disturbances are governed by the reconnection of small-scale magnetic field structures in the vicinity of coronal loop footpoints. The energy converted in the reconnection process is transported upwards by heat conduction. In the upper atmosphere, the apparent motion of the heat-front is then observed as a propagating disturbance.

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Talks: Session 3: Wednesday - 12:00

Coronal Loop Science with the Daniel K Inouye Solar Telescope

Tom Schad (National Solar Observatory)
The DKIST Team

The US National Science Foundation's Daniel K Inouye Solar Telescope is nearing the end of construction. Once in operations, DKIST will not only be the world's most powerful optical and infrared solar telescope but will also be the largest obscuration-free coronagraphic spectropolarimeter ever built for coronal science. This talk will highlight the unique capabilities that DKIST makes available for coronal loop science with a particular focus on the diagnostic capabilities of polarized spectral lines. DKIST offers new opportunities to measure the coronal magnetic field in and along loops. In particular, forbidden coronal emission lines in the infrared, as targeted by the DKIST's Diffraction-Limited Near IR Spectropolarimeter (DL-NIRSP) and the Cryogenic Near Infrared Spectropolarimeter (Cryo-NIRSP), provide sensitivity to the magnetic field intensity and direction via the polarization induced by the Zeeman Effect and radiative scattering. Since the involved atomic levels are both radiatively and collisionally populated, this talk also demonstrates how polarized measurements of forbidden emission lines may, under certain conditions, be used for single-line density diagnostics. In addition to hot coronal lines, DKIST and its suite of five facility instruments provides unprecedented coordinated measurements of many cool chromospheric lines that brightly emit in loops undergoing catastrophic cooling. With its large light collecting aperture and sensitive polarimeters, DKIST offers exciting possibilities to measure the coronal loop magnetic fields when they cool and radiate in chromospheric lines, in particular, in the polarizable He I triplet and the infrared Calcium triplet.

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Talks: Session 3: Wednesday - 14:00

Wave based coronal loop heating models (Invited)

Inigo Arregui (Instituto Astrofisica Canarias)

Observational evidence is clear about the presence of MHD waves in magnetic coronal loops. Well studied physical processes, such as resonance damping or phase mixing, provide means to cascade energy down to dissipative scales. Yet, quantifying the capacity and amount of heat that wave models can provide has proven difficult. Recent modelling efforts have focused on the numerical simulation of the non-linear and non-ideal dynamics of resonantly damped transverse waves together with Kelvin-Helmholtz unstable flows. As the relevant physics reaches progressively smaller spatial scales, it becomes increasingly difficult to obtain observational signatures to support wave heating processes from observations. The forward modelling of emission and spectral line characteristics from the simulations is helping to confront observations and models. Recent analyses on the effects of wave heating on the distribution of the differential emission measure arise as promising alternatives, with the advantage that they make possible the comparison to other heating mechanisms. This contribution aims at reviewing the latest modelling results and their connection to observations to assess the current status of wave based coronal loop heating mechanisms.

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Talks: Session 3: Wednesday - 14:30

Effect of the coronal loop density structure on the efficiency of wave heating

Paolo Pagano (University of St Andrews)
Richard Morton (Northumbria University), Ineke De Moortel (University of St Andrews)

Observations of coronal loops have revealed ubiquitous transverse velocity perturbations and estimates have shown that these perturbations carry a significant amount of energy, possibly sufficient to sustain the million degree solar corona.More recently, a clear power spectrum for these transverse oscillations has been identified providing clear indication of how much energy can be extracted from propagating waves.At the same time, MHD models still do not explain how this energy can be efficiently converted and the indications coming from the models suggest that the direct dissipation of waves is not a sufficiently efficient mechanism to heat the solar corona.The damping of transverse waves can be understood in terms of coupling of the transversal modes (kink) with azimuthal modes (Alfvén) in the inhomogeneous boundaries of the loops, which is also the region where the energy conversion is most efficient. In this work we investigate the role of the density structure of the loop, i.e. the region with density enhancement, in the efficiency of the wave heating mechanism. Using 3D non-ideal MHD simulation with a driver that simulates the observed power spectrum of transverse waves, we focus on two different loop structure; a traditional cylindrical one where a dense interior region exists along the whole loop length and another one where there is no interior region and the density enhancement extends only until a certain length along the loop.

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Talks: Session 3: Wednesday - 14:45

Superoscillations heat coronal plasma

Arturo Lopez Ariste (IRAP - CNRS)
M. Luna (IAC. Spain)

At certain places and times, a wave can oscillate much faster than its global frequency. These unexpected behaviour is dubbed a superoscillation, and often occurs near dislocations, places where the phase of the wave is undefined. Such superoscillations have been analytically predicted and found in solar magneto-acoustic waves propagating from sunspots into the corona.Local frequencies 10 times higher than the typical 5 mHz of waves in the corona are found. Associated to those high frequencies, viscous dissipation explodes and the plasma is heated. The heating rate can be computed analytically from the expressions of the propagating waves. When inserted in a 1d numerical simulation, the calculated heating rates are successful in heating the coronal plasma well beyond 10 million degrees in a few seconds.The heating is associated to the superoscillations, and these happen in very localized regions 1-2 arcsec across along the propagation direction of the wave, along the magnetic field. Thus, superoscillations appear to predict heating in coronal plasma along magnetic field lines in constant cross sections of 1-2 arcsec in what appears as a nice description of observed coronal loops.

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Talks: Session 3: Wednesday - 15:00

MHD Waves in Complex Magnetic Fields

Thomas Howson (University of St Andrews)

Ineke De Moortel (University of St Andrews), Jack Reid (University of St Andrews), Alan Hood (University of St Andrews)

Many previous studies have proposed the slow stressing of magnetic field and subsequent release of energy as a mechanism for maintaining the high temperature of coronal plasma. Whilst direct observational evidence of braided fields within the Sun's atmosphere remains elusive, if these models are representative, then we might expect significant field complexity to exist within coronal structures. Meanwhile, over the past 20 years, many observational studies have highlighted the abundance of wave power throughout the solar atmosphere. In this context, we present the results of three dimensional MHD simulations of propagating waves in complex magnetic fields. We discuss the observed wave dynamics, formation of small spatial scales and establish what may be inferred about the nature of the background plasma.

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Talks: Session 3: Wednesday - 16:15

Is "dark" energy needed in the solar corona? Investigating the correlation between Doppler velocities and non-thermal line widths

Tom Van Doorsselaere (KU Leuven)
Vaibhav Pant (KU Leuven), Norbert Magyar (KU Leuven), Richard J. Morton (Northumbria University)

After the advent of the Coronal Multi-Channel Polarimeter (CoMP), transverse waves have been ubiquitously observed in the solar corona. However, the transverse wave energy flux estimated from Doppler velocity measurements in the corona was found to be four orders of magnitude less than that estimated from coronal non-thermal line widths. Using a Monte Carlo simulation, McIntosh & De Pontieu (2012) suggested that this discrepancy in energy might be due to the line-of-sight (LOS) superposition of the several oscillating structures,which can lead to an underestimation of the transverse wave amplitudes. Their simulations also required the use of an additional, unknown source of unresolved wave or turbulent energy to provide agreement with measurements of coronal non-thermal line widths. McIntosh & De Pontieu (2012) termed this coronal "dark" energy.In our previous studies, we have found that transverse driving of loops with perpendicular density structuring leads to the new phenomena of uniturbulence. In this study, we extend our previous simulations with uniturbulence to include gravitational stratification, and investigate whether 'dark' energy can be self-consistently explained with the uniturbulence. We excite the transverse MHD waves with three different wave amplitudes at the bottom boundary of the simulations and forward model the simulation output with the FoMo tool to create synthetic observations for the Fe XIII emission linecentred at 10749 A. The Doppler velocities and non-thermal line widths are derived from the synthetic spectra at every location for different LOSs. We confirm that the LOS superposition greatly reduces the observed Dopplervelocity amplitudes and increases the non-thermal line widths of optically thin emission lines. Importantly, our model generates the observed wedge-shaped correlation between the root mean square (rms) Doppler velocitiesand non-thermal line widths without artificially adding any additional non-thermal line widths. Further, we find that the non-thermal line widths increase with increasing height above the solar limb. We computed the observedwave energy fluxes and found that they are only 0.7-1% of the true wave energy fluxes. This explains 2-3 orders of magnitude of the energy discrepancy in the corona, which is the result of the optically thin nature of the solar corona and poor spatial resolution of the CoMP. Using a wave-based MHD model, we conclusively establish that the true wave energies are hidden in the non-thermal line widths. Hence, our results rule out the requirement for a 'dark' energy in the solar corona, because it is self-consistently explained using uniturbulence.

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Talks: Session 3: Wednesday - 16:30

Damping of Propagating Kink Waves in the Solar Corona

Ajay Tiwari (Northumbria University)
Richard J. Morton (Northumbria),Stephane Regnier (Northumbria) ,James A. Mclaughlin (Northumbria)

Alfvénic waves have gained renewed interest since the existence of ubiquitous propagating kink waves were discovered in the corona. It has long been suggested that Alfvénic waves play an important role in coronal heating and the acceleration of the solar wind. To this effect, it is imperative to understand the mechanisms that enable their energy to be transferred to the plasma. Mode conversion via resonant absorption is believed to be one of the main mechanisms for kink wave damping and is considered to play a key role in the process of energy transfer. In this study, we examine the rate of damping of propagating kink waves in coronal loops observed using the Coronal Multi-channel Polarimeter (CoMP). In order to provide accurate estimates of damping lengths and quality factors for the waves, we discuss a suitable likelihood function for fitting models to the ratio of two power spectra obtained from discrete Fourier transforms. We compare this method with the previously used method of least-squares and highlight the limitations of least-squares. We are able to confirm earlier indications that the propagating kink waves are undergoing frequency dependent damping. Additionally, it is found that the rate of damping decreases, or equivalently the damping length increases, for longer coronal loops.

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Talks: Session 3: Wednesday - 16:45

Estimating the Heating Rate of Standing Alfvén Waves

Alexander Prokopyszyn (University of St Andrews)
Alan Hood (St Andrews), Ineke De Moortel (St Andrews)

Phase mixing of Alfvén waves has long been considered as a possible candidate for coronal heating. In this study, we estimate the heating rate associated with phase mixing of standing Alfvén waves. We use a 2.5D model and approximate the transition region as a perfect discontinuity, which allows us to obtain analytical solutions.The model builds on analytic work of previous authors by allowing an arbitrary factor of wave energy, R, to reflect and, 1 - R, to transmit through the transition region. We find that for ideal plasma, with $R < 1$, the wave energy in the corona always grows to a maximum value. Even for ideal plasma, the cross-field gradients converge to a finite value which means an upper bound for the cross-field gradients and hence the heating rate can be calculated. From this, we are able to derive a formula which could be useful for calculating the parameter space under which wave heating could be negligible or non-negligible.

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Talks: Session 4: Thursday - 09:00

Chromospheric/TR signatures of active region loop heating (Invited)

Vanessa Polito (Harvard-Smithsonian Center for Astrophysics)

Recent observations with high resolution instruments (such as Hi-C, IRIS and AIA) have shown rapid variability at small temporal and spatial scale at the footpoints of high temperature active region coronal loops. Such observations, combined with state of the art modelling, have provided significant insights into the heating processes and energy transport mechanisms in active region nanoflares. In particular, the chromospheric and TR observations are key to understanding the physical processes at play, since these are the sites of the bulk energy deposition. In this talk, I will review some of these recent findings, focusingon the comparison between theoretical predictions of different 1D hydrodynamic heating models (i.e. heating by non-thermal electrons, thermal conduction or Alfven waves) of coronal loops with chromosphere/TR diagnostics from IRIS.

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Talks: Session 4: Thursday - 09:30

Diagnostics of nanoflare heating in active region core loops from chromospheric and transition region observations and modeling

Paola Testa (Harvard-Smithsonian Center for Astrophysics)
Polito V. (CfA), De Pontieu B. (LMSAL, Oslo), Graham D. (BAERI), Reale F. (Univ.Palermo, INAF)

Rapid variability at the footpoints of active region coronal loops has been observed (Testa et al. 2013, 2014), and provides powerful diagnostics of the properties of coronal heating and energy transport(e.g., Testa et al. 2014, Polito et al. 2018).We will present results of our detailed analysis of a dozen of IRIS/AIA observations of footpoints brightenings associated with coronal heating, and will present the distribution of the observed properties (e.g.,duration of brightenings, intensity ratios, Doppler shifts, non-thermal broadening,..). We will discuss the properties of coronal heating as inferred from the coupling of these high spatial, spectral, and temporal resolution chromospheric/transition region/coronal observations, with modeling.We will also present results of a new algorithm we have developed for an automatic detection of these footpoint brightenings in AIA observations (Graham et al. 2019), which will allow us, in our next step, to significantly expand the number of events detected, and build morerobust statistics of the properties of nanoflares in active region loops.

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Talks: Session 4: Thursday - 09:45

Contribution to the transition region EUV emission from the low lying cool loops observed by IRIS

Clementina Sasso (INAF - Osservatorio Astronomico di Capodimonte)
Brooks, D. H. (College of Science, George Mason University), Andretta, V. (INAF - Osservatorio Astronomico di Capodimonte), Reep, J. W. (Space Science Division, Naval Research Laboratory)

In the past 30 years, different theories have been proposed and debated to explain the origin of the Transition Region (TR) emission at temperatures below 1 MK. The existence of low-lying cool loops, thermally insulated from the corona, has been indicated as an explanation for the increase of the differential emission measure (DEM) towards the chromosphere, but till some years ago there were no instruments with sufficient spatial resolution to confirm the existence of these unresolved fine structures (UFSs), as they were addressed by Feldman (1998). Only recently, the Interface Region Imaging Spectrograph (IRIS) observed numerous low-lying dynamic cool loops (Hansteen et al. 2014), showing proprieties that could account for these UFSs. Brooks et al. (2016) performed hydrodynamic simulations that suggested that these IRIS cool loops could be spatially resolved, i.e. they may be individual structures, and analyzed their proprieties, but the contribution of these structures to the TR emission has been not yet evaluated. With this work, we aim to calculate the DEMs from the simulations of these low-lying cool loops and compare them with the observed DEMs, and also with the DEMs resulting from dynamic cool loop models obtained in previous work (Sasso et al. 2015).

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Talks: Session 4: Thursday - 10:00

Doppler and non-thermal motions in transition region of active regions

Durgesh Tripathi (IUCAA, Pune)
Avyarthana Ghosh (IUCAA, Pune), James A Klimchuk (NASA, GSFC, USA)

A comprehensive understanding of Doppler and non-thermal motions is vital to understanding the transfer of mass and energy in the solar atmosphere. Here we measure these two parameters in an active region using the Si IV 1394 A spectral line from the Interface Region Imaging Spectrograph (IRIS). Also, we study their relationship with the photospheric magnetic field from Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). The active region has two opposite polarity strong field regions separated by a weak field corridor. The average Si IV properties are similar in the strong field regions and corridor. We find average redshifts of 5-10 km/s and 3-9 km/s in the strong field regions and corridor, respectively (depending on the date of observation), and average non-thermal velocities of $\sim$ 18-20 km/s and $\sim$16-18 km/s, respectively. There is, however, a narrow lane in the middle of the corridor where the Doppler shifts are near zero and the non-thermal velocities are significantly reduced. There is a suggestion that the average redshifts decrease toward the limb in both the strong field regions and corridor, but no definitive conclusion is possible. The non-thermal velocities have a strong positive correlation with redshifts but not blueshifts. This could be due to flows in unresolved strands along the line-of-sight. We suggest that the emission from the lower transition region comes primarily from warm type II spicules and introduce the idea of a "chromospheric wall" that is associated with classical cold spicules.

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Talks: Session 4: Thursday - 11:15

On the Detection of Periodic Flows in Loops Undergoing Thermal Non-Equilibrium

Gabriel Pelouze (Institut d'Astrophysique Spatiale)
G. Pelouze (IAS, Orsay, France), F. Auchère (IAS, Orsay, France), K. Bocchialini (IAS, Orsay, France), C. Froment (Rosseland Centre for Solar Physics, Univ. of Oslo, Norway; ITA, Univ. of Oslo, Norway), S. Parenti (IAS, Orsay, France), E. Soubrié (IAS,

Long-period intensity pulsations have been recently detected in coronal loops with EUV images of both SoHO/EIT (Auchère et al., 2014) and SDO/AIA (Froment et al., 2015). These pulsations have been interpreted as resulting from thermal non-equilibrium (TNE), thus providing a signature of a highly-stratified and quasi-constant heating at the loops footpoints (Froment et al., 2017; Auchère et al., 2016). Depending on the adequacy between the geometry of the loop and the characteristics of the heating, this can result in either complete (at chromospheric temperatures) or incomplete (T>1MK) condensation and evaporation cycles, that are responsible for the observed intensity pulsations. Using 1D hydrodynamic simulations, Froment et al. (2017) were able to reproduce the observed pulsations, with incomplete condensation for the active region studied in their previous paper. The simulations also predict periodic plasma flows along the loops footpoints, with velocities up to 40km/s.In order to detect these flows, we use time series of spatially resolved spectra from the EUV spectrometer Hinode/EIS. We systematically search for EIS datasets that correspond to the observation of pulsation events among the 3000+ that were detected in AIA data, between 2010 and 2016. For the 11 datasets that are found, we derive series of Doppler velocity maps, which allows us to track the evolution of the plasma velocity in the loop over several pulsation periods, and compare it to the results of previous simulations. We identify signatures of flows compatible with the expected pulsations in two of these datasets. We demonstrate that line of sight ambiguities, combined with low signal to noise ratio or lack of time cadence, can explain this low detection rate.

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Talks: Session 4: Thursday - 11:30

Multi-scale observations of thermal nonequilibrium cycles in coronal loops

Clara Froment (Rosseland Centre for Solar Physics (UiO))
P. Antolin (University of St. Andrews), V. Henriques (UiO), P. Kohutova (UiO), L. Rouppe van der Voort (UiO)

Long-period EUV pulsations in coronal loops have recently been found to be a common feature of active regions. These pulsations and the commonly observed coronal rain are in fact two aspects of the same phenomenon: thermal nonequilibrium (TNE). Indeed, these pulsations, with periods ranging from 2 to 16 hours, have been identified as the coronal counterpart of TNE cycles, i.e. evaporation and condensation cycles. These cycles are produced by highly-stratified and quasi-steady, long duration heating in coronal loops. As such, they reflect specific spatiotemporal characteristics of the heating mechanism.Here, we report unique observations that combine multiple instruments that capture the extremes of the spatial and thermodynamic scales covered by TNE processes: from the global multi-million K loop scale to the cool and dense chromospheric rain clumps of a few hundred km. Within the same coronal loop bundle, we captured long-period (6 hours) intensity pulsations in the coronal channels of SDO/AIA and coronal rain in chromospheric wavelengths of the CRISP and CHROMIS instruments at the Swedish 1-m Solar Telescope (SST). We present the thermal analysis of the cycles as well as an extensive spectral characterisation of the rain clumps that allows us to precisely measure the chromosphere-corona solar atmospheric mass and energy cycle during TNE.

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Talks: Session 4: Thursday - 11:45

Dynamics of coronal rain blobs

Ramon Oliver (University of the Balearic Islands)
Martínez Gómez, D. (Instituto de Astrofísica de Canarias, Spain), Khomenko, E. (Instituto de Astrofísica de Canarias, Spain), Collados, M. (Instituto de Astrofísica de Canarias, Spain)

Coronal rain is the final product of evaporation and condensation cycles that take place in active regions. Coronal rain occurs in the form of dense and cold blobs that fall down along coronal loops, with smaller than free-fall speed. We study the dynamics of a coronal rain condensation with two-dimensional MHD simulations. The blob is injected at t = 0 in an isothermal coronal loop that is vertically stratified by gravity. An upward pointing pressure gradient develops in a time-scale of 100 s. This force counteracts the acceleration of gravity and falling speeds of the order of tens of km/s are obtained, in agreement with observations. The maximum blob descending speed is correlated with the ratio of initial blob to loop density, which gives the possibility of measuring the blob density from its falling speed.

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Talks: Session 4: Thursday - 12:00

The Role of Asymmetries in Thermal Non-Equilibrium

James Klimchuk (NASA-GSFC)
Manuel Luna (Instituto de Astrofisica de Canarias)

Thermal non-equilibrium (TNE) is a fascinating situation that can occur when quasi-steady coronal heating, including impulsive heating with a high repetition frequency, is concentrated at low altitudes in the corona. No equilibrium exists, and as the atmosphere "searches" for one, it undergoes convulsions that typically, but not always, involve the formation of a cold condensation. This is the likely explanation of prominences, coronal rain, and long-period loop pulsations. Asymmetries in heating or flux tube cross-sectional area can have a major impact on the behavior. If the asymmetries are large enough, a steady flow develops rather than TNE. We here present two analytical formulae for predicting TNE, steady flow, or quasi-static equilibrium. We show that the predictions are in good agreement with 1D hydrodynamic simulations.

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Talks: Session 5: Thursday - 14:00

Stellar coronae and winds (Invited)

Moira Jardine (University of St Andrews)
Andrew Cameron (St Andrews)

Over the last decade, advances in spectropolarimetry have allowed us to map the surface magnetic fields of stars, revealing several surprising trends in the geometry of this large-scale field. One of the most fascinating results is that many rapidly rotating stars show strong toroidal (and mainly azimuthal) fields. The structure of the corona and wind will depend on how this toroidal field and its associated currents are distributed with height. In this talk I will review our understanding of geometry of the coronal magnetic fields of these stars and introduce a new method for probing this structure observationally, using modelling of the "slingshot prominences" trapped in the largest loops. I will also describe how these observations can inform our understanding of the elusive mass loss rates of the winds of solar-like stars.

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Talks: Session 5: Thursday - 14:30

Stellar Coronae: News, Puzzles, and Implications for the Past, Present and Future Sun (Invited)

Steven Saar (Harvard-Smithsonian CfA)

I highlight some of the latest results from stellar coronal research, new and ongoing puzzles, and some possible implications for where the Sun has been, what it is doing now, and where it may be headed, coronally speaking.

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Talks: Session 5: Thursday - 16:15

EUV and X-ray loops above active regions of different activity levels

Juxhin Zhuleku (Max Planck Institute for Solar System Research)
J. Warnecke , H. Peter (Max Planck Institute for Solar System Research, Göttingen, Germany)

The corona of the Sun and Sun-like stars, as observed in the EUV and X-ray, is dominated by magnetic loops. For the Sun we can model these magnetic structures in detail, e.g. reproducing the intensity distribution along loops or the 3D spatial structure. Stellar observations, on the other hand, extend the limited range of (magnetic) activity covered by solar structures. Thus, stellar observations can give constraints to models not available by solar observations. Hence, we model coronal active regions and their loops with different levels of activity to investigate to what extent this can recover observed stellar relations, e.g. between X-ray luminosity and surface magnetic flux. With 3D MHD models of solar active regions we can recover many aspects of the loop-dominated coronal structure and dynamics. Our goal is to study how coronal loops respond to higher levels of surface magnetic activity representative for a more active star. We present a series of numerical experiments where we change the surface magnetic flux in the photosphere while keeping other model parameters the same. Using the Pencil Code we solve the MHD equations where the corona is heated mainly by Ohmic dissipations. The currents are induced by driving the surface magnetic field through photospheric motions. From our 3D models we can synthesize the EUV and the X-ray emission and investigate the relation between coronal emission and magnetic flux. Depending on the magnetic flux at the surface, the modeled coronae reach peak temperatures ranging from 1 to 10 MK. The average temperature and density of the coronal part of the computational domain somewhat follows the well-known RTV scaling laws. EUV and X-ray emission we synthesize from the model increases steeply with the unsigned magnetic flux at the surface. Our findings indicate that a higher magnetic flux at the surface allows for a higher efficiency in energy transport into the upper atmosphere in the fieldline braiding or fluxtube tectonics scenario. This implies that the upward Poynting flux behaves differently for different levels of surface magnetic flux.

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Talks: Session 5: Thursday - 16:30

The Sun as a star in the EUV

Giulio Del Zanna (University of Cambridge)

I present recent modelling of the EUV irradiances in spectral lines emitted by the quiet Sun (Del Zanna 2019), using as a baseline SDO/EVE data and CHIANTI v.10 atomic data. There is an excellent agreement between theory and observation, with the exception of a few low-temperature lines, and an indication that the coronal chemical abundances are photospheric. I then review the variations of the EUV irradiances during the 1998-2014 period. These studies are a basis for semi-empirical modelling of EUV irradiances of other stars. Finally, I describe how useful spectroscopic diagnostics are in the EUV to study stellar coronae, in the framework of SIRIUS, one of the FAST missions under evaluation by ESA.

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Talks: Session 3: Friday - 09:00

Reconnection-based coronal loop heating models (Invited)

David Pontin (University of Dundee)

Amongst the many proposed mechanisms for heating coronal loops, magnetic reconnection often plays a prominent role. These include the magnetic field line braiding model of Parker, coronal tectonics, and flux emergence and cancellation. Here I will review these 'DC' heating mechanisms, with an emphasis on theory and numerical simulations.

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Talks: Session 3: Friday - 09:30

Elementary Heating Events in 3D Radiative MHD Simulations of Coronal Flux Tubes

Jeffrey Reep (US Naval Research Laboratory)

Ignacio Ugarte-Urra (US Naval Research Laboratory), Russell B. Dahlburg (US Naval Research Laboratory), Giorgio Einaudi (George Mason University), Harry P. Warren (US Naval Research Laboratory)

One of the leading theories of coronal heating is that numerous small-scale reconnection events drive the conversion of magnetic energy to internal and kinetic energy in coronal plasma. We use a simulation of a 100 Mm loop performed with the 3D radiative magnetohydrodynamic code Hyperion3D to study reconnection events in a coronal loop. Using a combination of thresholding and clustering methods, we have devised a detection method to determine the locations, volumes, spatial extents, and durations of the elementary events in the simulation. We discuss the method and the statistics of the events that occur within the simulation. Our initial results suggest that they occur at high frequency, producing quasi-steady heating, which maintains the corona.

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Talks: Session 3: Friday - 09:45

Analytical 3D Magnetohydrostatic Equilibria for Modelling Solar Magnetic Fields

Thomas Neukirch (University of St Andrews)
Thomas Wiegelmann (Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany)

Accurately measuring the magnetic field in the solar corona is extremely difficult and hence our knowledge of the coronal magnetic field structure relies on the extrapolation of magnetic field measurements in the lower regions of the solar atmosphere into the corona. Whereas solar corona generally is a domain of low plasma-beta with largely force-free magnetic fields, this is not the case for the parts of the solar atmosphere where the magnetic is measured and the magnetic fields there should be calculated using (non-force-free) magnetohydrostatic equilibria. In this contribution we present a new family of analytical magnetohydrostatic equilibria which can be used as relatively simple and computationally cheap alternative to numerical modelling methods. These equilibria have the capability of combining a non-force-free layer with a domain of linear force-free magnetic field, including a transition between these two domains. The methodology used to calculated these equilibria is based on work by Low (e.g. Low 1991) in the form given by Neukirch and Rastätter (1999). Potential applications to modelling solar magnetic fields will be discussed. Low, B.C., ApJ 370, 427, Neukirch, T. & Rastätter, L., A&A 348, 1000

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Talks: Session 3: Friday - 11:15

Thermodynamic Evolution of the Tearing Instability

Erin Goldstraw (University of St Andrews)
Alan Hood (University of St Andrews)

Slow convective motions inject energy into the coronal magnetic field. Under suitable conditions, this stored energy can be released as heat in the corona. One mechanism for this is reconnection, which can be triggered by the tearing mode instability. In order to model the plasma response to this heating, thermodynamic processes need to be considered.Full MHD simulations of a coronal field, driven at its photospheric footpoints are presented. Initially, the magnetic field evolves through a sequence of equilibria, before a symmetry breaking perturbation triggers the tearing mode. Optically thin radiation and thermal conduction are included to investigate the effect of thermodynamic processes on the system.

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Talks: Session 3: Friday - 11:30

The Onset of 3D Magnetic Reconnection in the Solar Corona

Lars K. S. Daldorff (GSFC/CUA)
James E. Leake (GSFC/NASA), James A. Klimchuk (GSFC/NASA), Kalman Knizhnik (NRC/Postdoctoral Research Associate)

Magnetic reconnection, one of the most important processes in the universe, is believed to be initiated in most cases by the tearing instability of an electric current sheet. Whether and how the tearing develops nonlinearly and releases substantial amounts of magnetic free energy depends on the relative growth rates of the different normal modes that are allowed in the system. In the general case where there is a guide field—in which the field rotates across the sheet by a shear angle—there exist both parallel modes centered on the sheet and oblique modes offset from it. We have performed a series of resistive magnetohydrodynamic (MHD) simulations of weakly perturbed, triply periodic current sheets with conditions appropriate to the solar corona to study how the different modes evolve and interact. We find three primary evolutionary paths: (1) a parallel mode dominates and saturates at a level that releases only a small amount of energy, but is large enough to choke off the growth of other modes; (2) parallel and oblique modes grow at nearly the same rate and interact violently as they become nonlinear, releasing a large amount of energy; (3) subharmonics of the fastest growing parallel mode induce a coalescence of islands, also releasing a large amount of energy. Which path will be taken depends in a predictable way on the length, thickness, and shear angle of the current sheet, as well as the resistivity. A critical issue is whether the wavelength of the fastest growing mode is longer or shorter than the current sheet, i.e., whether subharmonics exist. We expect all three behaviors on the Sun. These results have important implications for the question of reconnection onset. Observed phenomena require the buildup of high levels of magnetic stress before reconnection switches on to release the stored magnetic energy.

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Talks: Session 3: Friday - 11:45

Field line winding and tangling in the solar corona

Simon Candelaresi (University of Dundee)
David Pontin, Anthony Yeates, Paul Bushby, Gunnar Hornig

Using HMI magnetogram data and magneto-convection simulations we determine the degree of winding and tangling of surface-anchored magnetic field lines in the solar corona. For that we use the measure of finite time topological entropy and the normalised winding rate. We show that the surface motions of simulated convection zone and the observed photospheric motions are very efficient in tangling anchored field lines. For the considered plage region we find that in ca. 3 hours the plasma is able to induce a winding of similar complexity as the highly efficient reference flow that induces a pig tail braid.

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Talks: Session 3: Friday - 12:00

MHD avalanches: heating of coronal loops

Jack Reid (University of St Andrews)

J. Reid (University of St Andrews), A. W. Hood (University of St Andrews), P. J. Cargill (Imperial College London, University of St Andrews), C. E. Parnell (University of St Andrews), C. D. Johnston (University of St Andrews)

Of the many proposals for coronal heating, the nanoflare model of Parker argues that coronal loops are heated by releases of magnetic energy in several, small-scale events, proceeding from magnetic reconnection.Our investigation seeks to verify the viability of continual photospheric driving of the coronal magnetic field causing an ongoing series of reconnection events, powering a succession of heating events and forming a magnetohydrodynamic (MHD) 'avalanche'.In a three-dimensional MHD simulation, we model the creation, twisting, and instability of threads composing a coronal loop, with a view to determining the resultant heating distribution.From this is found an impulsive, spatially distributed, and highly confined heating.Analysing its distribution, we form profiles of the heating, and then use these to investigate the prospective field-aligned thermal response within the plasma, including in discussing its ability to maintain possibly coronal conditions, with plausible temperatures and densities.

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Talks: Session 3: Friday - 14:00

General Discussion

Fleck/Klimchuk ()

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Posters

P1: Spicules and the off-limb emission from the transition region

Vincenzo Andretta (INAF/Osservatorio Astronomico di Capodimonte)
D. Schmit (NASA/GSFC), J. A. Klimchuk (NASA/GSFC), C. Sasso (INAF/OAC), B. Fleck (ESA)

Spicules are prominent features of the off-limb solar atmosphere in chromospheric and transition-region (TR) lines. It is therefore natural to suggest that they might be an important if not the dominant source of emission at temperatures of the order of 0.1 MK or lower.We address this issue by identifying a representative set of spicules in IRIS slit-jaw images at the solar limb and measuring their intensity profiles as a function of height. These measurements are then combined to derive an estimate of total off-limb emission of the Sun at TR temperatures in several realistic scenarios of the spicule distribution over the solar surface. The resulting computed off-limb intensity profiles are then compared with measurements of the observed off-limb solar emission as function of height.We finally discuss these results in the context of the closely related issue concerning the role that small-scale structures - the so-called Unresolved Fine Structures (UFSs) - can play in the output budget of the transition region.

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P2: Simulating nanoflares in the solar atmosphere: Analysis of synthetic observables

Helle Bakke (Rosseland Centre for Solar Physics (UiO))
Lars Frogner (Rosseland Centre for Solar Physics), Boris Vilhelm Gudiksen (Rosseland Centre for Solar Physics)

The extreme temperatures of the solar corona are continuously studied through observations and numerical modelling. The heating processes are connected to the magnetic field, but it is not yet determined how these processes work. We investigate the energy deposition of non-thermal electrons accelerated by magnetic reconnection in nanoflares through 3D numerical modelling of the solar atmosphere. In order to enhance the realism of magnetohydrodynamic (MHD) simulations, we introduce a simple method for accelerated electrons to transport energy from reconnection sites into the lower atmosphere. The method was run for a short amount of time, and was compared to an almost identical simulation without accelerated electrons. Spectral line synthesis of Mg II h&k revealed a clear effect on the observables at the energy deposition site. The result implies that heating by accelerated electrons from nanoflares is necessary in order to model the upper solar atmosphere to a high precision. Future analysis of synthetic observables will be extended to other spectral diagnostics, such as from NASA's Interface Region Imaging Spectrograph (IRIS), NASA's Solar Dynamics Observatory (SDO) and the Swedish 1-m Solar Telescope (SST) on La Palma.

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P3: Solar flare simulation and observations: a spatiotemporal analysis of the magnetic field, electric current density and Lorentz force

Krzysztof Barczynski (LESIA, Observatoire de Paris, Universite PSL, Sorbonne Universite, Meudon)
Krzysztof Barczynski1, Guillaume Aulanier1, Sophie Masson1, (LESIA, Observatoire de Paris, Universite PSL, Sorbonne Universite, Meudon1), Michael W. Wheatland2, (Sydney Institute for Astronomy, School of Physics, University of Sydney, Australia2)

We discuss dependencies of magnetic field, electric current density and Lorentz force in erupting flare. In addition, we focus on different methods of Lorentz force calculation. The high-spatiotemporal resolution of the 3D simulation outputs allows us a detailed study of the morphology, evolution, and dynamics, giving us a new view of processes occur in the solar flares. We compare our results of the 3D simulation with observational studies. We find that the contraction of the inflow of the magnetic fields is determined by the currents and Lorentz forces. Additionally, we show that the surface integral coming from the volume integral of the Maxwell stress tensor, as usually used in observational data analysis as the proxy of the Lorentz force, present a different behaviour than the Lorentz force itself. The Lorentz force characterises more complicated morphology than mentioned integrand. Moreover, based on the analysis of the induction equation in the simulation, we unveil that the increase of the horizontal magnetic filed around active region PILs during eruptions is solely and exclusively result of the flare reconnection-driven contraction of flare loops. Using our simulation and observations of several flares, we found clear decrease of Jz at the footpoints of the flux rope. These findings can be important in flare diagnostic.

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P4: Predictions of DKIST/DL-NIRSP observations for an off-limb kink-unstable coronal loop

Gert Botha (Northumbria University)
GJJ Botha (Northumbria), B Snow (Exeter), E Scullion (Northumbria), JA McLaughlin (Northumbria) PR Young (NASA Goddard), SA Jaeggli (NSO)

A 3D non-eruptive kink-unstable coronal flux rope is simulated by solving numerically the nonlinear magnetohydrodynamic equations with parallel thermal conduction. A highly twisted loop observed in TRACE 171 provides the loop dimensions and initial physical parameters. The time evolution from the initial unstable equilibrium is forward modelled by generating synthetic intensity maps using DKIST/DL-NIRSP spectral lines computed with CHIANTI. These are used to predict observational signatures by the new Daniel K Inouye Solar Telescope (DKIST) in the coronal off-limb mode of its Diffraction Limited Near Infrared Spectropolarimeter (DL-NIRSP) instrument. The reconstructed large field-of-view intensity mosaics and single tile sit-and-stare high-cadence image sequences show detailed, fine-scale structure and exhibit signatures of wave propagation, redistribution of heat, flows, and fine-scale bursts. The DKIST/DL-NIRSP signatures of the twisted flux and the associated instability are compared and contrasted with Hinode/EIS images that are generated for rasters (moving slit) and sit-and-stare (stationary slit) observational modes.

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P5: Solar coronal abundances and the stellar connection

David Brooks (George Mason University @ JAXA)
Harry Warren (Naval Research Laboratory), Deborah Baker (University College London), Lidia van-Driel Gesztelyi (University College London, Observatoire de Paris, Konkoly Observatory)

The solar upper atmosphere shows distinctive patterns of elemental abundances that are different from that of the photosphere. Low first ionization potential (FIP $<$ 10 eV) elements are generally enhanced relative to high FIP elements. Since the fractionation process occurs in the chromosphere, the FIP effect is a unique diagnostic of the flow of mass and energy in coronal loops. A similar FIP effect is seen in the atmospheres of some solar-like stars, while late-type M stars show an inverse (I)FIP effect. The elemental composition thus appears to be related to fundamental stellar properties such as rotation, surface gravity, and spectral type. Using observations from SDO/EVE, we have found that when the Sun is observed as a star, the coronal composition and Ne/O abundance ratio show a variation with the solar cycle phase, introducing an uncertainty and magnetic activity dependence into the nature of any relationship between coronal composition and fixed stellar properties, with implications also for the "solar modeling problem". Furthermore, the inverse FIP effect was recently detected on the Sun during solar flares, allowing a very detailed look at the spatial and temporal behavior that is not possible from stellar observations. We present recent work on the spatial and temporal variability of the FIP and IFIP effect in active regions, discuss clues to how the IFIP process occurs, and present a new diagnostic that allows us to determine whether low/high FIP elements are depleted/enhanced in specific IFIP events. These results highlight the significance of detailed solar observations for understanding the heating processes in stellar atmospheres.

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P6: Coronal loops numerical simulation using adapted semi-empirical structure models

Sandra Milena Conde Cuellar (University of São Paulo)
Sandra M. Conde (University of São Paulo), Carlos E. Cedeño (Brazilian Center for Physics Research)

Coronal loops are fascinating structures visible in EUV images. The study of the loop structure variables can pave the way to understand their contribution to the solar atmosphere heating. In this work, we present a description of the distribution of the physical variables in a simulated and observed loop. To do so, we obtain our observational data from the AIA and HMI instruments of SDO in order to compare our simulated results with real loops. In this simulation, we adjust four atmospheric semi-empirical models for quiet and active Sun to analyse our results.

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P7: NuSTAR observations of loops heated repeatedly by microflares

Kristopher Cooper (University of Glasgow)
I. G. Hannah (Glasgow), H. S. Hudson (Glasgow/UCB), B. W. Grefenstette (Caltech), S. Krucker (UCB/FHNW), D. M. Smith (UCSC), L. Glesener (UMN)

We present several microflares from a recently emerged active region, AR12721, that were observed on 2018 September 9-10. Using both the Nuclear Spectroscopic Telescope Array (NuSTAR) and the Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO/AIA) the temporal, spatial, and spectral evolution of the microflares can be studied to determine the energy released, and the associated heating of coronal loops. NuSTAR is an astrophysical X-ray telescope, with direct imaging spectroscopy providing a unique sensitivity for observing the Sun above 2.5 keV. The active region microflares were below GOES A1 equivalent level, and the X-ray emission observed by NuSTAR peaks several minutes earlier than the EUV emission seen by SDO/AIA. The heated loops are clearly visible in Fe18 from SDO/AIA, as well as the X-ray images from NuSTAR. From the NuSTAR X-ray spectra, we find that the temperature in some of the microflares reached up to 8 MK but even at the time of peak emission the microflares are clearly multi-thermal.

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P8: Microflares in the cores of active regions

Giulio Del Zanna (University of Cambridge)
Urmila Mitra-Kraev

We present some case studies of microflares. We focus on small events, below the GOES threshold, but still clearly observable with instruments such as Hinode XRT, Hinode EIS, SDO/AIA. These events are very common in active region (AR) cores, are short-lived (10 minutes) and appear to be resolved at the AIA resolution in the Fe XVIII emission within the AIA 94 A band. It is important to study their evolution and see if they contribute to the steady AR heating. When possible, we combine AIA, XRT and EIS simultaneous observations to measure the plasma state. We find good agreement between the temperatures obtained from EIS and the isothermal temperatures obtained from the XRT filter ratios, although some relative calibration issues between the EIS< XRT, and AIA instruments are present. We show that even a small increase in temperature leads to a significant increase in the Fe XVIII emission in the AIA 94 A band. The microflare temperatures are often much lower than 7 MK, the peak Fe XVIII abundance in equilibrium. We also revisit with new atomic data the temperatures measured by a SoHO SUMER observation of an active region which produced microflares, also finding low temperatures (4 MK), confirming previous measurements based on Yohkoh instruments, where temperatures in the range 2-8 MK were found.

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P9: Using spatio-temporal analysis of transverse loop oscillations

Tim Duckenfield (Centre for Fusion, Space and Astrophysics, University of Warwick)
C. Goddard (Centre for Fusion, Space and Astrophysics, University of Warwick), V. M. Nakariakov (School of Space Research, Kyung Hee University, Korea), D. J. Pascoe (Centre for Mathematical Plasma Astrophysics, KU Leuven, Belgium)

Coronal loops are known to exhibit many transverse oscillations, ascribed to MHD fast mode kink oscillations. Using coronal seismology to extract information about local plasma conditions from oscillation properties is often limited by an abundance of free parameters. This can be ameliorated using additional information from higher harmonics of the oscillation's fundamental mode. The aim of this contribution is to show how analysis of a loop oscillation's spectral components, both spatially and temporally, can determine the presence of any longitudinal harmonics and their properties. Comparing the properties of these different harmonics such as phase, period and damping times, better constraints can be made on the resulting seismology. The ratio of harmonic period to fundamental period is determined by the loop's longitudinal distribution of kink speed, whilst relative phase between different harmonics is determined by the excitation mechanism. Classical resonant absorption theory relates signal quality factor to the density contrast of the loop, its transverse density structure and inhomogeneous layer thickness. Thus any difference between different harmonics' quality factors could be attributed to density profiles at different spatial positions. We show several examples of how the information from higher harmonics can be used in these ways, and how the results of this analysis are pushing at the limits of current observational capabilities. Generally, since transverse oscillations have been revealed to be ubiquitous in the corona, the use of higher longitudinal harmonics contributes to the future routine application of seismology on all coronal loops.

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P10: Can the kappa-distributions be detected from MaGIXS spectra?

Jaroslav Dudík (Astronomical Institute of the Czech Academy of Sciences)
J. Dudik, E. Dzifcakova (Astronomical Institute of the Czech Academy of Sciences), G. Del Zanna, H. E. Mason (DAMTP, University of Cambridge), L. Golub (Harvard-Smithsonian Centre for Astrophysics), A. R. Winebarger, S. L. Savage (NASA Marshall Space Flig

The upcoming flight of the Marshall Grazing-Incidence Spectrometer (MaGIXS) will observe the solar spectrum at 6-24 A, dominated by emission of hot coronal plasma. We investigate the possibility of detecting the non-Maxwellian kappa-distributions by using the lines of Fe XVII and XVIII, which should be strong and numerous in MaGIXS spectra. It is found that many line ratios are sensitive to both the temperature and kappa. Best diagnostic options are provided by line ratios involving both Fe XVII and Fe XVIII lines, in combination with another ratio of lines formed within a single ion. In addition, when combined with the Fe XVIII 93.93 A line routinely observed by AIA, much higher sensitivity, of about a factor of 2-3, can be obtained. The MaGIXS instrument is thus well-suited for detection of non-Maxwellian distributions.

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P11: Simulating nanoflares in the solar atmosphere: Energy transport and deposition

Lars Frogner (Rosseland Centre for Solar Physics (University of Oslo))
Helle Bakke (Rosseland Centre for Solar Physics), Boris Vilhelm Gudiksen (Rosseland Centre for Solar Physics)

Solar nanoflares are believed to occur in great numbers, and their collective heating has been proposed as a possible explanation for the high temperature of the corona. Although existing 1D numerical models have provided great insight into the behaviour of individual flares, realistic 3D simulations are needed to examine how flares collectively influence the atmosphere. We introduce a model for the energy transport from magnetic reconnection sites to the lower solar atmosphere via accelerated electron beams. The model is integrated it into the 3D radiative magnetohydrodynamics code Bifrost. A preliminary simulation with relatively low reconnection energies is run for only a short duration, but still leads to clear changes in the observables at sites where the electron beams thermalise. In future work we will study the effects of the model in more detail.

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P12: Establishing Observational Signatures from Coronal Braiding

Lianne Fyfe (University of St Andrews)
L.Fyfe (St Andrews), I.De Moortel (St Andrews), T.Howson (St Andrews)

Closing the gap between observations and numerical models is a critical step in helping us to identify the mechanism(s) responsible for coronal heating. Through the use of forward modelling, we can transform the model results into synthetic emission data, allowing us to compare models and observations in a meaningful way. We present the results of numerical simulations investigating the braiding of two coronal magnetic flux tubes. Using forward modelling, we infer if there are any observational signatures associated with this particular model's heating mechanisms. We discuss the evolution of synthetic intensities and Doppler velocities in order to predict observables which would highlight the existence of such processes in the Sun's atmosphere. Analysing such results from multiple heating models will allow us to identify characteristics of energy release in the solar corona.

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P13: Using EUV SDO/AIA data to undertake a comprehensive survey of coronal limb loop width evolution over a solar cycle

Daniel Gass (University of Central Lancashire)
Prof. Robert Walsh (University of Central Lancashire)

NASA's SDO/AIA instrument has over ten years of continuous EUV observations of the solar atmosphere. Most AIA studies limit themselves to short time periods (or even single images) around specific events and as yet we have not properly exploited the full potential of this longitudinal dataset. As such, we risk missing possible long-term trends in a range observable features. However, given the quantity of data, advanced and appropriate data processing techniques (such as machine learning and automated feature tracing) need to be employed for long term trend evaluation of fundamental structures.This work describes preliminary results from a multi-wavelength EUV coronal survey of limb loops, taken from ten years of AIA data created to investigate fundamental properties of these coronal structures. The data reduction, image enhancement (through a Multiscale Gaussian Normalisation (MGN) approach) and subsequent pattern recognition algorithms will be introduced. Coronal loop widths in particular will be analysed to investigate and quantify any potential correlation between the phase of the solar cycle and the energy distribution within the corona. Going forward, the role of machine learning within the project is likely to be significant and possible ways to address this are outlined.

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P14: Oscillation amplitudes and energy fluxes of simulated decayless kink oscillations.

Konstantinos Karampelas (KU Leuven)
T. Van Doorsselaere (KU Leuven), D. Pascoe (KU Leuven), M. Guo (Institute of space sciences, Shandong University), (KU Leuven), Patrick Antolin (University of St. Andrews)

Recent observations with the Atmospheric Imaging Assembly (AIA) instrument on the SDO spacecraft have revealed the existence of decayless coronal kink oscillations. These transverse oscillations are not connected to any external phenomena like flares or coronal mass ejections, and show significantly lower amplitudes than the externally excited decaying oscillations. Numerical studies have managed to reproduce such decayless oscillations in the form of footpoint driven standing waves in coronal loops, and to treat them as a possible mechanism for wave heating of the solar corona. Our aim is to investigate the correlation between the observed amplitudes of the oscillations and input the energy flux from different drivers. We perform 3D MHD simulations in single, straight, density-enhanced coronal flux tubes for different drivers, in the presence of gravity. Synthetic images at different spectral lines are constructed with the use of the FoMo code. The development of the Kelvin-Helmholtz instability leads to mixing of plasma between the flux tube and the hot corona. Once the KHI is fully developed, the amplitudes of the decayless oscillations show only a weak correlation with the driver strength. We find that low amplitude decayless kink oscillations may correspond to significant energy fluxes of the order of the radiative losses for the Quiet Sun. A clear correlation between the input energy flux and the observed amplitudes from our synthetic imaging data cannot be established. Stronger drivers lead to higher vales of the line width estimated energy fluxes. Finally, estimations of the energy fluxes by spectroscopic data are affected by the LOS angle, favoring combined analysis of imaging and spectroscopic data for single oscillating loops.

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P15: Propagating torsional oscillation of a chromospheric surge

Petra Kohutova (University of Oslo)
Erwin Verwichte, Clara Froment

Torsional (or Alfvén) oscillations of magnetic structures have been theoretically predicted for decades. Previous detections of such oscillations so far have however mostly relied on indirect signatures, such as periodic broadening of spectral line width. We present a first direct observation of a fully resolved torsional oscillation of a surge of plasma at chromospheric temperatures associated with a partial prominence eruption. The IRIS spectral data provides a clear evidence of the oscillation of the LOS velocity with 180° phase difference at the opposite edges of the surge flux-tube. This together with an alternating tilt in the Si IV and Mg II k spectra across the flux-tube and the trajectories traced by the individual threads of the surge material provides a clear evidence of the rotational motion of the flux-tube in alternating directions. We hence identify the motion as a propagating torsional oscillation with $\sim$ 90 s period.

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P16: Idealized and Data-Constrained 3D MHD Modeling of Prominence Formation

Roberto Lionello (Predictive Science Inc.)
T. Török (PSI), C. Downs (PSI), Z. Mikić (PSI), V.S. Titov (PSI)

The formation of prominences belongs to the most important open questions in solar physics. There exists a consensus that prominence plasma has to be of chromospheric origin, but the mechanism(s) by which it accumulates in the corona are still not well understood. The presently most accepted scenario invokes the evaporation of chromospheric plasma by foot-point heating and its subsequent condensation in the corona by thermal non-equilibrium. This scenario has been successfully modeled in 1D hydrodynamic simulations along single field lines of static magnetic fields, but a more appropriate, fully 3D treatment has been started just very recently.Here we present our recent, fully 3D MHD simulations of prominence formation via plasma evaporation and condensation. We first consider fully time-dependent, idealized magnetic flux-rope configurations, and impose a relatively simple background heating of the corona combined with localized foot-point heating to obtain prominence-like condensations. We discuss the properties and evolution of the plasma for these cases.We then present a simulation of prominence formation within a data-constrained flux-rope configuration, which was developed to represent the pre-eruptive state of the 14 July 2000 "Bastille Day" eruption (Török et al. 2018). In this simulation, a more complex heating model is used, and we employ a technique that "freezes" the 3D magnetic field. The latter ensures that the plasma evolution is governed by the thermodynamics alone (Mok et al., 2005) and, which significantly facilitates its analysis via comparison with 1D simulations performed along selected field lines.

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P17: Diagnostics of non-Maxwellian distributions in the solar corona

Juraj Lorincik (Charles University in Prague, Astronomical Institute of the Czech Academy of Sciences)
Jaroslav Dudik (Astronomical Institute of the Czech Academy of Sciences), Giulio Del Zanna (DATMP, CMS, University of Cambridge, UK), Elena Dzifcakova (Astronomical Institute of the Czech Academy of Sciences)

Recent works have shown that solar emission spectra, particularly those from the corona, can strongly be affected by presence of non-Maxwellian electron distributions. For example, the κ-distributions, in which parameter κ (kappa) encodes the system's departure from the Maxwellian (thermal) distribution. These have already been diagnosed e.g. in the solar wind, flares, and transition region. However, unambiguous evidence of these non-Maxwellian distributions in the solar corona is at present difficult due the calibration uncertainty of the Hinode/EIS instrument.Here we report on diagnostics of κ-distributions in the solar corona observed with Hinode/EIS. We used multiple spectral atlases containing observations of active regions and the quiet Sun observed in 2006 - 2007, thus avoid problems with instrument sensitivity degradation. Line intensities were averaged for various structures, such as coronal loops, moss, and quiet Sun. After background subtraction we excluded missing pixels off the statistics and fitted emission lines of Fe XI-XVI needed for diagnostics of plasma.Diagnostics of density, temperature, DEM, and electron distributions is performed utilizing observed ratios of line intensities. Synthetic spectra were computed using Chianti, v.8. While densities can be determined quite well, we were only capable of diagnosing a range of possible values of κ for each of the observed structures. Nevertheless, the results for off-limb quiet Sun indicate that this part of the corona is Maxwellian.

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P18: Fundamental vibrations of the solar corona

Manuel Luna (Instituto de Astrofísica de Canarias (IAC))
R. Oliver (Universitat de les Illes Balears), P. Antolin (University of St Andrews) & I. Arregui (Instituto de Astrofísica de Canarias)

Some high-resolution observations of the solar corona suggest that it is formed by myriads of small tubes called strands. Furthermore, small amplitude transverse MHD oscillations are ubiquitously observed in coronal loops. The small-amplitude oscillations of the strands could be coupled forming collective oscillations involving large regions of the solar corona. In this work, we study the normal modes of the solar corona associated with its fine structure. We consider systems with various numbers of strands. We find that these systems can sustain a huge number of normal modes whose periods split with respect to the individual kink mode period. The width of the period band depends on the properties of the fine structure. The normal modes consist of clusters of strands vibrating in complex ways. We have generated synthetic Dopplergrams and we have found that in the same line-of-sight (LOS), the strands move in many directions producing a reduction of the integrated velocity and subsequently a small Doppler signal. However, the resulting Doppler signal does not systematically decrease with strand number as in randomly distributed velocity systems. The clustering between strands leads to bursts of Doppler velocity lasting a few minutes, whose amplitudes are reduced by the LOS superposition. We have also found that these vibrations contribute to the non-thermal line broadening. We conclude that these vibrations associated with the fine structure can contribute to the hidden "dark" wave energy content of the corona.

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P19: Temperature structure of a sigmoidal active region

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Active regions often show S-shaped topology called 'Sigmoid' in the core of active regions. The S-shaped coronal structures, which are highly sheared and twisted, are observed along the polarity inversion line in the active region and are considered to be one of the best pre-eruption signatures. Here, we present a detailed study of an on-disk sigmoid observed on December 26, 2015, to understand its thermodynamic evolution. For this purpose, we have employed differential emission measure (DEM) and filter ratios techniques on the observations recorded by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) and X-ray Telescope (XRT) on board Hinode. We measured the temperature of sigmoid using DEM during the impulsive rise (7-8 MK), peak (10 MK) and decay phase (7 MK) of the C 1.6 GOES X-ray flare. We estimated emission from the Fe XVIII (93.932) line in sigmoid using AIA 94 channel and confirmed that the emission comes from the peak formation temperature of Fe XVIII (7.1 MK). The temperature obtained from DEM found to be in good agreement with the temperature obtained using the XRT filter ratio as well as GOES temperature. These results provide important ingredients for the thermodynamics modeling of structures in the core of active regions.

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P20: Coronal Loop Seismology Using Kink Oscillations in Loops with Wide Inhomogeneous Layers

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The transverse structure of coronal loops plays a key role in the physics but the small transverse scales can be difficult to observe directly. For wider loops the density profile may be estimated by forward modelling of the transverse intensity profile. The transverse density profile may also be estimated seismologically using kink oscillations in coronal loops. The strong damping of kink oscillations is attributed to resonant absorption and the damping profile contains information about the transverse structure of the loop. However, the analytical descriptions for damping by resonant absorption presently only describe the behaviour for thin inhomogeneous layers. Previous numerical studies have demonstrated that this thin boundary approximation produces poor estimates of the damping behaviour in loops with wider inhomogeneous layers. Both the seismological and forward modelling approaches suggest loops have a range of layer widths and so there is a need for a description of the damping behaviour that accurately describes such loops. We perform a parametric study of the damping of standing kink oscillations by resonant absorption for a wide range of inhomogeneous layer widths and density contrast ratios, with a focus on the values most relevant to observational cases. We describe the damping profile produced by our numerical simulations without prior assumption of its shape and compile our results into a lookup table which may be used to produce accurate seismological estimates for kink oscillation observations.

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P21: Volume-filling simulations of coronal loops heated by nanoflares

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We present results of a coronal simulation consisting of loop strands that fill the coronal volume in a self-consistent fashion. The simulation is heated by a fully controllable 3D distribution, which can be specified independent of the loop geometry and can include nanoflares and continuous heating. The simulation is applied to a small example active region and used to produce synthetic AIA data, which are then processed to produce a distribution of coronal EUV brightening events. This distribution is then compared with that found in the real AIA data for the same region, and we use the results to determine if the observations are consistent with our prescribed heating distribution.

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P22: The Effect of Anisotropic Viscosity on the Kink Instability

Jamie Quinn (University of Glasgow)
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Presented is a model of anisotropic viscosity suitable for the solar corona. Due to the form of the full Braginskii viscous stress tensor, numerical errors are common in regions of weak field in simulations. The anisotropic model that we present, the "switching model", captures the main physics of viscosity in the corona and can be applied in regions of weak field. The switching model is based on a physically motivated interpolation between the isotropic and strong-field parallel Braginskii stress tensors and we have implemented this model in Lare3D.The switching model is used to investigate the effect of anisotropic viscosity on the nonlinear evolution of the helical kink instability in a coronal loop, and we compare results with those using purely isotropic viscosity. Although the switching model is designed to function well in weak field, the field of the kink instability is strong enough throughout the domain so that the switching model reduces to the purely parallel Braginskii model. We show that the anisotropic viscosity has a quantifiable effect on the behaviour of kinetic energy, Ohmic heating, and magnetic relaxation.

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P23: Strong viscous damping of coronal Alfvén waves

Alexander Russell (University of Dundee)

The viscous damping of Alfvén waves under coronal conditions is revisited, and found to be a factor around 10^9 stronger than previously recognised. The implications for coronal waves and coronal heating will be discussed.

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P24: Automated Detection of Magnetic Structures at the Boundary of the Closed Corona

Roger Scott (University of Dundee)
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The topology of coronal magnetic fields near the open-closed magnetic flux boundary is important to the process of interchange reconnection (IR), whereby plasma is exchanged between open and closed flux domains. Various topological and morphological configurations can participate in IR, and each is likely to have a unique 'signature' in its contribution to the slow solar wind. Using a volumetric measure of the magnetic squashing factor (Q) we identify magnetic structures in the coronal volume and associate these with linear features in Q maps at the source surface. Then, applying image analysis and segmentation techniques along with automated feature detection, we perform a survey of a representative collection of coronal field models and make inferences on the rate of occurrence of individual structures. The analysis techniques that we employ, which are commonplace in medical and biological sciences, have not been previously applied to studies of coronal models, and so this work represents a first attempt to assess the utility such methods, which can be very powerful but are also subject to certain limitations.

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P25: Simulation of dynamics of hot plasma in postflare loops

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We investigate dynamics of hot plasma in postflare coronal loops using MHD modeling and calculating synthetic images/fluxes in various SDO channels and other spectral bands - GOES and Mg XII 8.42 A spectral line.Our aim is to investigate dynamics of evaporation and condensation/draining of hot plasma in postflare loops. We use 2D and 3D MHD simulations, start with loop-like initial magnetic field and realistic plasma parameters. For the solving of MHD equations we use MPI-AMRVAC code with gravity, thermal conduction and radiative loses. We apply arbitrary heating in the chromosphere which mimic chromospheric heating by the energetic electrons from the reconnection region. The plasma starts to evaporate and soon fills the overlying magnetic loop system. The observed plasma characteristics - temperature, density, flow, and their dynamics strongly depend on adopted physical conditions. In particular, strength of magnetic field plays important role, as well as heating rate, depth and the size of the heated region.To constrain the possible range of parameters we calculate synthetic images/fluxes in various EUV and X-ray channels with the use of the FoMo code. We compare calculated images with observational data (we chose one large-scale and one small-scale loop associated with $\sim$B-class flares) and identify probable physical conditions, in which synthetic data match observations. We were able to find heating regimes to match the observations; beside we see several interesting features that can be revealed only in 2D or 3D modeling.

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P26: Coronal Density and Temperature Profiles Calculated by Forward Modelling EUV Emission Observed by SDO/AIA

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We present a model for the intensity of optically thin EUV emission for a plasma atmosphere. We apply our model to the solar corona as observed using the six optically thin EUV channels of the SDO/AIA instrument.The emissivity of the plasma is calculated from the density and temperature using CHIANTI tables and the intensity is then determined by integration along the line of sight.We consider several different profiles for the radial density and temperature profiles, each of which are constrained by the observational data alone with no further physical assumptions.We demonstrate the method first by applying it to a quiet region of the corona, and then use it as the background component of a model including coronal holes, allowing the plasma densities and temperatures inside and outside the hole to be estimated.We compare our results with differential emission measure (DEM) inversions.More accurate estimates for the coronal density and temperature profiles have the potential to help constrain plasma properties such as the magnetic field strength when used in combination with methods such as seismology.

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P27: Energy release and atmospheric response during flux cancellation

Petros Syntelis (University of St Andrews)
P. Syntelis, E.R. Priest, L.P. Chitta

Recent observations at high spatial resolution have shown that magnetic flux cancellation occurs on the solar surface much more frequently than previously thought. In Priest et al. 2018 we proposed magnetic reconnection driven by photospheric flux cancellation as a mechanism for chromospheric and coronal heating. In particular, we estimated analytically the amount of energy released as heat and the height of the energy release during flux cancellation. In Syntelis et al. 2019, we set up a two-dimensional resistive MHD simulation of two canceling polarities in the presence of a horizontal external field and a stratified atmosphere in order to check and improve upon the analytical estimates. Computational evaluation of the energy release during reconnection is found to be in good qualitative agreement with the analytical estimates. In addition, we performed an initial study of the atmospheric response to reconnection. We find that, during the cancellation, either hot ejections or cool ones or a combination of both hot and cool ejections can be formed, depending on the height of the reconnection location. The hot structures can have the density and temperature of coronal loops, while the cooler structures are suggestive of surges and large spicules.

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P28: Observations from the GOES-R Solar UltraViolet Imager Extended Coronal Imaging Campaign

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Geostationary Operational Environmental Satellite (GOES)-16 and GOES-17 each hosts a Solar UltraViolet Imager (SUVI) that images the Sun in six extreme ultraviolet (EUV) wavelengths: 9.4 nm, 13.1nm, 17.1nm, 19.5nm, 28.4nm, and 30.4nm. The SUVI is nominally Sun-pointed and has a four-minute imaging sequence covering all the channels and meeting the dynamic range requirements. Based on the SUVI capabilities observed on-orbit, a campaign to image the extended solar corona was undertaken in 2018. This was performed by off-pointing the SUVI line-of-sight to the left and right of the Sun and producing a composite image by stitching together the off-pointed and the Sun-centered images in the 17.1nm and 19.5nm channels. The imaging area in the composite is about three times the nominal image area in the East-West direction (about 5 RSun versus 1.6 RSun for nominal images). The campaign was conducted in February (4 hours), June (72 hours), and August-September of 2018 (5 weeks). Results from the campaign indicated the presence of solar corona to three solar radii, even in the quiet Sun part of the solar cycle. Limited solar CME activity during the 5-week campaign was observed in both the SUVI and LASCO C2 imagers. The white light coronal structures that are seen during the short total solar eclipses are not normally captured by the orbiting solar EUV imagers due to the emphasis on observing the features on the solar disk and the limitations of the imaging devices. The large dynamic range and the anti-blooming nature of the SUVI CCD enabled the recording of interesting coronal features - both near and far from the solar disk - during this campaign and should of interest to researchers with MHD models. Preliminary analysis results from the 2018 campaign will be presented. Current plan is to execute the campaign for a few months in 2019 with the SUVI on GOES-17 and the status will be discussed.

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P29: Flux Rope Formation Due to Shearing and Zipper Reconnection

James Threlfall (University of St Andrews)
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Zipper reconnection has been proposed as a mechanism for creating most of the twist in the flux tubes that are present prior to eruptive flares and coronal mass ejections.In this contribution, I will describe our results from several numerical experiments which aim to study this new regime of reconnection. In one model, two initially untwisted parallel flux tubes are sheared and reconnect to form a large twisted flux rope. I will expand on several aspects of this initial investigation, which have already been published in Threlfall et al. 2018, Solar Physics, 293, 98. I will also explore more recent improvements to the model and how these changes affect our previous findings. Finally, I will also describe some of our (ongoing) attempts to expand this initial concept to include further additional flux tubes in more general configurations.

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P30: The Magnetic Properties of High-Temperature Active Region Loops: Observations and Numerical simulations

Ignacio Ugarte-Urra (US Naval Research Laboratory)
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One of the key problems in solar physics is understanding the influence of the magnetic field in coronal heating. Detailed studies of the magnetic properties of impulsively heated loops have been, however, rare. We present results from a study of 34 evolving coronal loops observed in the Fe XVIII line component of AIA/SDO 94 Å filter images from three active regions with different magnetic conditions. We show that the peak intensity per unit cross-section of the loops depends on their individual magnetic and geometric properties. The intensity scales proportionally to the average field strength along the loop (Bavg) and inversely with the loop length (L) for a combined dependence of (Bavg/L)0.52±0.13. These loop properties are inferred from magnetic extrapolations of the photospheric HMI/SDO line-of-sight and vector magnetic field in three approximations: potential and two Non Linear Force-Free (NLFF) methods. Through hydrodynamic modeling (EBTEL model) we show that this behavior is compatible with impulsively heated loops with a volumetric heating rate that scales as eH ∼ (Bavg0.3±0.2/L0.2±0.1). We finally compare these results with how the Fe XVIII emission scales with B and L in a parameter search performed with Hyperion, a code that solves the compressible magnetohydrodynamic (MHD) equations in 3D with parallel thermal conduction and optically thin radiation and where heating is due to the resistive and viscous dissipation induced in the corona by footpoint shuffling.

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P31: Recurrent dynamics of a coronal loop registered with MgXII spectroheliograph

Artem Ulyanov (P.N. Lebedev Physical Institute)
A. Reva (P.N. Lebedev Physical Institute)

We report on unique observations of recurrent asymmetric dynamics of coronal loop registered on 29 January, 2002 with MgXII SXR spectroheliograph. The studied event occurred within a hot on-limb lambda-shaped loop. The event started with a sudden burst near one of the loop footpoints that was later propagated to the opposite side of the loop and reflected backwards. The speed of the perturbation amounted to more than 290 km/s.The design of MgXII spectroheliograph allowed for the measurements of Doppler shift and broadening which can be used as a rough estimate of LOS-velocity and temperature of coronal plasma. The calculated Doppler velocity of the leading edge of the burst amounted to 120 km/s. During the event the loop temperature rose to over 10 MK.Our interpretation of the event implies that it was caused by an asymmetric flare that leaded to an explosive chromospheric evaporation followed by a generation of a shock wave. We derived a simple analytical model to verify this interpretation. We also used numeric 1D MHD-modeling to clarify the details of the event.

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P32: Chromospheric evaporation due to phase mixing of Alfvén waves

Hendrik-Jan Van Damme (University of St Andrews)
Ineke De Moortel (University of St Andrews), Paolo Pagano (University of St Andrews)

Observational evidence has shown that waves are ubiquitous in the solar corona. As such, the role of wave-based heating mechanisms is attracting increased attention. In particular, phase mixing of Alfvén waves has been proposed as a possible mechanism to accelerate the dissipation of wave energy. Using MHD simulations, we consider a 2D magnetic strand in hydrostatic equilibrium as a model for a coronal loop, and we investigate the chromospheric evaporation due to heating by phase mixing of Alfvén waves. We implement a continuous, sinusoidal driver that generates propagating Alfvén waves along the loop. Due to the non-uniform density profile, these Alfvén waves dissipate through phase mixing and increase the temperature in the boundary of the loop. In this study, we investigate whether this leads to chromospheric evaporation and whether the subsequent change in the local coronal density is sufficient to alter the phase mixing process.

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P33: Simulating the Coronal Evolution and Eruption of Bipolar Active Regions

Stephanie Yardley (University of St Andrews)
Duncah H. Mackay (University of St Andrews), Lucie M. Green (MSSL/UCL)

To gain a better understanding of the formation and evolution of the pre-eruptive structure of CMEs requires the direct measurement of the coronal magnetic field, which is currently very difficult. An alternative approach, such as using the photospheric magnetic field as a boundary condition to simulate a time series of the coronal field must be used to infer the pre-eruptive magnetic structure and coronal evolution prior to eruption. The evolution of the coronal magnetic field of a small sub-set of bipolar active regions is simulated by applying the magnetofrictonal relaxation technique of Mackay et al. (2011). A sequence of photospheric line-of-sight magnetograms produced by SDO/HMI are used to drive the simulation and continuously evolve the coronal magnetic field of the active regions through a series of non-linear force-free equilibria. The simulation is started during the first stages of active region emergence so that the full evolution from emergence to decay can be simulated. A comparison of the simulation results with SDO/AIA observations show that many aspects of the observed coronal evolution of the active regions can be reproduced, including the majority of eruptions associated with the regions.

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P34: Propagating and standing MHD waves in multi-layered asymmetric waveguides

Noemi Kinga Zsamberger (University of Sheffield)
Matthew Allcock (University of Sheffield),William Oxley (University of Sheffield), Daria Shukhobodskaia (University of Sheffield), Robertus Erdelyi (University of Sheffield)

We present important advances in using multi-layered asymmetric waveguide models of the solar atmosphere. Several leaps forward have been made in recent years by developing these generalisations of the classical (symmetric) slab configuration. We provide an overview of these models and their applications using high-resolution solar observations.Magnetohydrodynamic (MHD) waves, by means of applying the methods of solar magneto-seismology (SMS), constitute a powerful tool to tackle a great challenge of solar physics: to diagnose the solar plasma in a range of MHD waveguides, from large structures like prominences, to small magnetic bright points (MBPs) and pores. We outline the framework of a new model of asymmetric waveguides to describe MHD wave propagation in the highly inhomogeneous solar atmosphere. First, we describe the general case of a multi-layered, stationary MHD waveguide. Then, we discuss its asymmetric (externally magnetic and non-magnetic) one-slab special cases, detailing the nature of propagating and standing MHD waves in the slab. Additionally, we investigate the effect of one or more steady bulk flows on the dispersion and stability of propagating MHD waves in an asymmetric magnetic slab.Concurrent with these theoretical advances, new developments abound in high-resolution solar observations. Once we have these practical results, each of the models can be utilised to describe different features in the solar atmosphere, such as elongated MBPs, light walls, fibrils, prominences, and CME flanks. We demonstrate a sample of these applications, as well as the SMS diagnostic power of waveguide asymmetry in solar structures.

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