RAS SD Meeting “Non-Equilibrium Thermodynamics in the Solar Atmosphere and Interior”

Start Date
Fri, 11/10/2024 - 10:35
End Date
Fri, 11/10/2024 - 15:35
Venue
The Royal Astronomical Society, Burlington House, London
Webpage
https://ras.ac.uk/events-and-meetings/ras-meetings/non-equilibrium-thermodynamics-solar-atmosphere-and-interior

Programme[1]

10:00 - 10:30 Coffee

10:30 - 13:00 Morning Session (*Chair: Patrick Antolin*)

10:30 – 10:35	Welcome (*Dmitrii Kolotkov*)
10:35 – 11:00	*Seray Sahin* *(invited):* From Chromospheric Evaporation to Coronal Rain: An Investigation of the Mass and Energy Cycle of a Flare
11:00 – 11:25	*Sudip Mandal* *(invited, remote):* Waves in the solar corona: Recent results from the Solar Orbiter mission
11:25 – 11:40	*Valery M. Nakariakov:* The effect of coronal heating misbalance on magnetoacoustic waves
11:40 – 11:55	*Dmitrii Zavershinskii (remote):* On some aspects of the dispersion of slow magnetoacoustic waves associated with thermal misbalance, thermal conductivity and coronal loop geometry
11:55 – 12:10	*Sergey Belov:* The Impact of Non-Local Thermal Transport and Finite Ion-Electron Equilibration on Compressive Waves in Coronal Loops
12:10 – 12:25	*Derteev Sergei B., Mikhalyaev Badma B. (remote):* Formation of two-periodic propagating disturbances in the solar corona
12:25 – 12:40	*Ben Snow:* Heating and cooling in partially-ionised shocks
12:40 – 12:55	*Balveer Singh:* Origin and Mass-Energy Transport Processes of Cool Jets in the Sun’s Atmosphere
12:55 – 13:00	Buffer time

13:00 – 14:00 Lunch[2]

[1] All time slots are given in British Summer Time (GMT+1). For abstracts, see below.
[2] Many eateries can be found locally in Piccadilly. Fellows wishing to bring food back to Burlington House are free to eat it in the Fellows Room.

14:00 – 15:35 Afternoon Session (*Chair: Anne-Marie Broomhall*)

14:00 – 14:25	*Jordan Philidet (invited):* Non-adiabatic surface effects in helio- and asteroseismology
14:25 – 14:50	*Veronika Jercic (invited, remote):* Simulations of prominences and coronal rain
14:50 – 15:05	*Tim Waters (remote):* Catastrophic cooling instability
15:05 – 15:20	*Patrick Antolin:* Disambiguation between Cool and Hot Emission in Instrument Passbands
15:20 – 15:35	*Ramada Sukarmadji:* Which comes first: Reconnection or waves? A chicken or egg conundrum in the solar corona

15:35 – 16:00 Tea

16:00 – 17:00 RAS Monthly A&G Highlights meeting

Abstracts

Ramada Sukarmadji (Northumbria University)

Title:
Which comes first: Reconnection or waves? A chicken or egg conundrum in the solar corona

Abstract:
A major coronal heating theory based on magnetic reconnection relies on the existence of braided magnetic field structures in the corona. In numerical simulations of braided loop-like structures, stress-induced reconnection shows the reconnected magnetic field lines driven sideways and overshooting from their new rest position and leading to low-amplitude transverse MHD waves. This provides an efficient mechanism for wave generation, but it has never been directly observed. With the recent discovery of nanojets, which are small (< ~1500 km in length), short-lived (< ~25 s timescales), and transverse to the guide field jet-like bursts, we are able to identify locations where small-angle reconnection takes place. Nanojets occur in a variety of structures including loops and flares, and we have also observed low-amplitude transverse MHD waves in a coronal loop triggered by the reconnection (identified by nanojets). This discovery provides major support to existing theories that transverse MHD waves can be a signature of reconnection, and the coronal reconnection scenario identified by nanojets. To understand this interplay between waves and reconnection, we present numerical simulation results of nanojets based on the model in Antolin et al. (2021), which is of two straight and adjacent flux tubes driven to form a small misalignment. MHD waves are introduced through footpoint driving, and we conducted a parameter investigation of the effects of footpoint driving on the reconnection by varying the driving amplitudes. Our results show that driving the footpoints with amplitudes of 10km/s and larger produces a singular nanojet-like formation event characterised by the fast bi-directional flows, while smaller driving amplitudes produce smaller scale and bursty reconnection events or continuous energy release without clear nanojet-like features. In all cases, the simulations

suggest that magnetic reconnection can be triggered by propagating MHD waves in a braided field, whilst also producing MHD waves with periods on a similar order to the observed waves produced by nanojets.

Jordan Philidet (Observatoire de Paris / PSL)

Title:
Non-adiabatic surface effects in helio- and asteroseismology

Abstract:
In solar-like oscillators in general, and in the Sun in particular, there is a well-known discrepancy, referred to as surface effects, between the seismic frequencies predicted by stellar models, and the observed frequencies. This is, in part, because stellar models fail to accurately represent the structure of the surface layers of these stars, and in particular their thermal structure, but also because of the immense challenge that the non-adiabatic interplay between turbulent convection and acoustic oscillations poses to the theory of asteroseismology. The surface effects constitute the main obstacle preventing us from exploiting all the asteroseismic data for solar-type oscillators, and if left uncorrected, lead to severely biased seismic determination of stellar masses, radii, and ages. As such, improving p-mode frequency predictions by accurately modelling surface effects is crucial to both helio- and asteroseismology, and stellar and solar physics in general. During this presentation, I will review the theoretical efforts that solar and stellar physicists have developed to more accurately model the non-adiabatic surface effects in the Sun, and in solar-like oscillators in general.

Sudip Mandal (Max Planck Institute for Solar System Research)

Title:
Waves in the solar corona: Recent results from the Solar Orbiter mission

Abstract:
Magnetohydrodynamic (MHD) waves have a significant impact on shaping the outermost layer of the Sun, known as the solar corona. Space-based telescopes such as the Atmospheric Imaging Assembly (AIA) onboard Solar Dynamics Observatory (SDO) have provided valuable insights into how these waves interact with the coronal plasma. For instance, they have helped us understand the damping of slow waves in different coronal structures, as well as the interaction of two regimes of kink waves. The recently launched Solar Orbiter has provided even more detailed spatial and temporal data of the solar corona, revealing fascinating new aspects of these phenomena. In my presentation, I will share new findings from the Solar Orbiter, building upon previous results, and discuss the potential for future research in this area.

Balveer Singh (Department of Mathematics, School of Science and Engineering, University of Dundee)

Title:
Origin and Mass-Energy Transport Processes of Cool Jets in the Sun’s Atmosphere

Abstract:
Solar cool jets are high-velocity, impulsive, and collimated plasma motions aligned with magnetic field lines in the Sun's atmosphere. Multiwavelength observations have detected small-scale cool jets (T < 0.1 MK) and their associated plasma processes such as MHD waves and oscillations, Instabilities etc. To deeply understand their physics, we employ numerical modeling using magnetohydrodynamics (MHD) theory. We present extensive 2-D and 2.5-D MHD numerical models in both ideal and non-ideal plasma in single and two-fluid regime elucidating the origin and evolution of these cool jets and associated plasma processes. Our findings align with various observations of cool chromospheric jets, enhancing our understanding of the intricate relationship between plasma flows and the complex structuring of the magnetic field. This relationship is crucial for the evolution of various triggering processes of these jets in the solar atmosphere. Additionally, our findings provide insights into their significant role in energy and mass transport into the lower solar corona. Specifically, we investigate the formation of spicule-like cool jets and associated plasma dynamics using 2-D and 2.5-D MHD modeling with Alfven pulses, and vertical velocity pulses in single as well as two-fluid regime. We examine the triggering mechanisms, dynamical evolution, kinematics, and energetics of these cool jets. Our results indicate that the transported mass flux and kinetic energy density during jet evolution are substantial enough to compensate for localized coronal losses. Non-adiabatic conditions, such as thermal conduction and radiative cooling, significantly influence jet propagation, mass flux, and kinetic energy density. We also notice that the mass motions associated with these cool jets generate in situ quasi-periodic oscillations on the scale of ~ 4.0 min above the transition region.

Dmitrii Zavershinskii (Samara National Research University)

Title:
On some aspects of the dispersion of slow magnetoacoustic waves associated with thermal misbalance, thermal conductivity and coronal loop geometry

Abstract:
This study investigates some aspects of the dispersion properties of slow magnetoacoustic waves in hot coronal loops for plasma diagnostic problems. Thermal misbalance, thermal conduction, and waveguide dispersion due to loop geometry have been considered as sources of wave dispersion. It is shown that in some cases the combination of dispersion effects can lead to the fact that the phase velocity for any possible period does not reach the value of the adiabatic speed of sound. For problems of imposing constraints on the unknown coronal heating function, the modified tube speed becomes an important characteristic velocity. The latter owes its origin to the joint influence of thermal misbalance and waveguide dispersion and acts as a high-period limit of the phase velocity of slow waves. In addition, it is shown that in the short-period range not only the isothermal speed of sound but also the isothermal tube speed can serve as good estimates of phase velocity.

Valery M. Nakariakov (University of Warwick)

Title:
The effect of coronal heating misbalance on magnetoacoustic waves

Abstract:
The existence of the solar corona requires a balance between energy loss and gain processes, i.e., the cooling by radiation and thermal conduction, and the unknown heating mechanism. Regardless of the specific heating process, cooling and heating functions depend differently on the macroscopic parameters of coronal plasma. Wave motions in the corona, which perturb the local density, temperature, and magnetic field, cause thermal misbalance. The long-lived nature of coronal plasma structures suggests stability to these perturbations, yet thermal misbalance, in turn, influences the waves. This back-reaction leads to wave dispersion, modifies dissipation, may cause wave overstability, and provides a diagnostic tool for estimating the coronal heating function through seismology.

Veronika Jercic (Centre for mathematical Plasma-Astrophysics, KU Leuven)

Title:
Simulations of prominences and coronal rain

Abstract:
Solar prominences and coronal rain are cold and dense plasma structures embedded in a hot and tenuous solar corona. Although found in the corona, prominences are rooted in the lower layers of the solar atmosphere and, as such, allow the coupling of different layers of it. There is more than one theory on the formation of these structures and satisfactory details on it and the corresponding conditions are still lacking. We focus on understanding the process of prominence formation, more specifically the evaporation condensation process. We ask in what way different triggering mechanisms affect the resulting thermal instability, that is, the resulting prominence and coronal rain. To achieve this, we compare the steady vs. stochastic type of localised heating. We perform two 2.5D simulations using an open source MPI-AMRVAC code. We show how different forms of localised heating that induce thermal instability result in prominences with different properties. The differences range from large-scale topological differences to small-scale dynamics. There is even evidence that localised heating can influence the appearance of reconnection. Furthermore, in the stochastic heating case, as the condensations are highly dynamic, they exhibit a form of transverse oscillations similar to the vertically polarised oscillations found in observations. We discuss the main differences between the two different prominences that form and we emphasise how it is all relatable to observations.

Seray Sahin (Antalya Bilim University & Northumbria University)

Title:
From Chromospheric Evaporation to Coronal Rain: An Investigation of the Mass and Energy Cycle of a Flare

Abstract:
Chromospheric evaporation (CE) and coronal rain (CR) represent two crucial phenomena encompassing the circulation of mass and energy during solar flares. While CE marks the start of the hot inflow into the flaring loop, CR marks the end, indicating the outflow in the form of cool and dense condensations. With the Interface Region Imaging Spectrograph (IRIS) and the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory, we examine and compare the evolution, dynamics, morphology, and energetics of the CR and CE during a C2.1 flare. The CE is directly observed in imaging and spectra in the Fe xxi line with IRIS and in the Fe xviii line of AIA, with upward average total speeds of 138 ± 35 km s^-1 and a temperature of 9.03 ± 3.28 x 10^6 K. An explosive-to-gentle CE transition is observed, with an apparent reduction in turbulence. From quiescent to gradual flare phase, the amount and density of CR increase by a factor of ‚âà4.4 and 6, respectively. The rain's velocity increases by a factor of 1.4, in agreement with gas pressure drag. In contrast, the clump width variation is negligible. The location and morphology of CE match closely those of the rain showers, with similar CE substructure to the rain strands, reflecting fundamental scales of mass and energy transport. We obtain a CR outflow mass three times larger than the CE inflow mass, suggesting the presence of unresolved CE, perhaps at higher temperatures. The CR energy corresponds to half that of the CE. These results suggest an essential role of CR in the mass-energy cycle of a flare.

Sergei B. Derteev, Badma B. Mikhalyaev (Kalmyk State University named after B.B. Gorodovikov, Department of Theoretical Physics)

Title:
Formation of two-periodic propagating disturbances in the solar corona

Abstract:
For several decades, propagating intensity disturbances (PDs) have been observed in the solar corona, which are interpreted as compressive waves. Observational data indicate the presence of jet-like features as a result of small-scale reconnections at the base of the corona, which may be responsible for the generation of PDs. Many authors proposed a theoretical description of PDs by acoustic and slow magnetoacoustic waves, where the effects of nonlinearity, viscosity, thermal conductivity, radiation and gravitational stratification are considered. We studied this phenomenon based on our previously proposed model of non-adiabatic waves in a high-temperature plasma, which takes into account the properties of the thermal conduction, radiative cooling and constant heating. Thermal conductivity forms a local minimum of group speed, separating groups of waves with short and long periods. Waves of the first group have strong dispersion and weak damping, waves of the second group have the opposite properties. Using this property, we simulated an initially localized wave packet. We assume that the form of PDs can indeed arise in the corona under the influence of small-scale disturbances in the lower atmosphere. The initial pulse disturbance eventually acquires a form, in which the indicated groups of components are clearly separated. Two maxima appear in the wavelet spectrum which determine the short and long periods. Two groups of waves with dominant periods propagate at the same speed, which is less than the sound speed. Thus, we attempted to extend the mechanism of formation of quasi-periodic oscillations of Roberts, Edwin and Benz to the case of damped acoustic waves.

For plasma density and temperature values , typical for the corona, we obtained period values close to those observed.

Patrick Antolin (Northumbria University)

Title:
Disambiguation between Cool and Hot Emission in Instrument Passbands

Abstract:
Narrowband ultraviolet (UV) or extreme ultraviolet (EUV) imagers, despite being relatively narrow, typically include significant contribution from more than one ion, thus leading to uncertainty regarding the temperature of the observed plasma. This is particularly limiting for diagnostic purposes of very hot or cool plasmas, whose sole presence in the solar corona can be attributed to specific physical mechanisms such as magnetic reconnection or thermal instability. The ambiguity is particularly large when observing off-limb, where line-of-sight superposition is maximal and the diffuse, hot emission becomes comparable in intensity to that of clumpy, cool structures such as spicules, coronal rain and prominences. In this work we investigate 3 methods based on temperature and morphology that are able to distinguish the cool and hot emission, and apply them to the AIA 304, SJI 1330 and SJI 1440 passbands. The methods are based on the Differential Emission Measure (DEM), a linear decomposition of the AIA response functions (RFit) and the Blind Source Separation (BSS) technique. All three methods are found to produce satisfactory results in both quiescent and flaring conditions, decomposing each image into a pair, one with the hot diffuse corona and another with the cool material off-limb in sharp contrast with the background. For AIA 304 we compare our results with co-aligned IRIS data in the SJI 1400 and 2796 channels, and find the RFit method to best match the quantity and evolution of the cool material detected with IRIS. These methods are in principle applicable to any passband from any instrument suffering from similar cool and hot emission ambiguity as long as there is good coverage of the hot temperature range.

Ben Snow (University of Exeter)

Title:
Heating and cooling in partially-ionised shocks

Abstract:
Shocks are an intrinsic element of the solar atmosphere, driven by fast magnetic reconnection and wave steepening. When shocks form low in the solar atmosphere, the effect of partial ionisation must be included whereby ionised and neutral species can decouple leading to a wealth of new phenomena. Here I present two-fluid numerical simulations of partialy-ionised shocks including collisional and radiative ionisation and recombination, and self-consistent heating and radiative cooling models allowing for the NLTE states within the shock to be studied, along with their feedback on the plasma and the resultant heating and cooling. The results show that two-fluid shocks behave significantly differently to their MHD analogues, with enhanced compression and greatly reduced temperature both in the post-shock region, and within the shock itself. The strong radiative losses caused by collisional ionisation remove thermal energy from the system, lowering the temperature. In some cases, the energy loss

can result in a near-isothermal temperature jump across the shock. As such, non-equilibrium ionisation is an important effect in the thermal evolution of shocks in the solar atmosphere.

Tim Waters (Los Alamos National Laboratory)

Title:
Catastrophic cooling instability

Abstract:
The solar corona is the prototypical example of a low density environment heated to high temperatures by external sources. The plasma cools radiatively, and because it is optically thin to this radiation, it becomes possible to model the density, velocity, and temperature structure of the system by modifying the MHD equations to include an energy source term that approximates the local heating and cooling rates. The solutions can be highly inhomogeneous and even multiphase because the well known linear instability associated with this source term, thermal instability, leads to a catastrophic heating and cooling of the plasma in the nonlinear regime. Here we show that there is a separate, much simpler linear instability accompanying this source term that can rival thermal instability in dynamical importance. The linear stability criterion is the isochoric one identified by Parker (1953), and we demonstrate that cooling functions derived from collisional ionization equilibrium are highly prone to violating this criterion.

Sergey Belov (University of Warwick)

Title:
The Impact of Non-Local Thermal Transport and Finite Ion-Electron Equilibration on Compressive Waves in Coronal Loops

Abstract:
Observations using slow waves as a seismological tool suggest that heat conduction in hot coronal plasma may be suppressed compared to the predictions of the classical thermal transport model. This suppression could be attributed to the effects of non-local thermal transport, which predicts preheating and the reduction of heat fluxes. In this study, we numerically compared the influence of local and non-local thermal transport models on standing slow waves in one-temperature and two-temperature coronal loops. To quantify this comparison, we focused on the period and damping time of the waves, as these are commonly observed parameters. Our findings revealed that non-local thermal transport can significantly impact standing slow waves in relatively rarefied cold or warm coronal loops, where the deviation from the local model exceeds 10%. Furthermore, we discovered that non-local thermal transport can either shorten or lengthen slow-wave damping times compared to the local model, due to the suppression of the isothermal regime. For hot coronal loops, no significant difference was found when compared to the local thermal transport. However, in these loops, we observed that finite equilibration between electron and ion temperatures can lead to damping times that are up to 50% longer than those predicted by the one-temperature model. These results indicate that non-local thermal transport can influence the dynamics of compressive waves across a wide range of coronal plasma conditions.