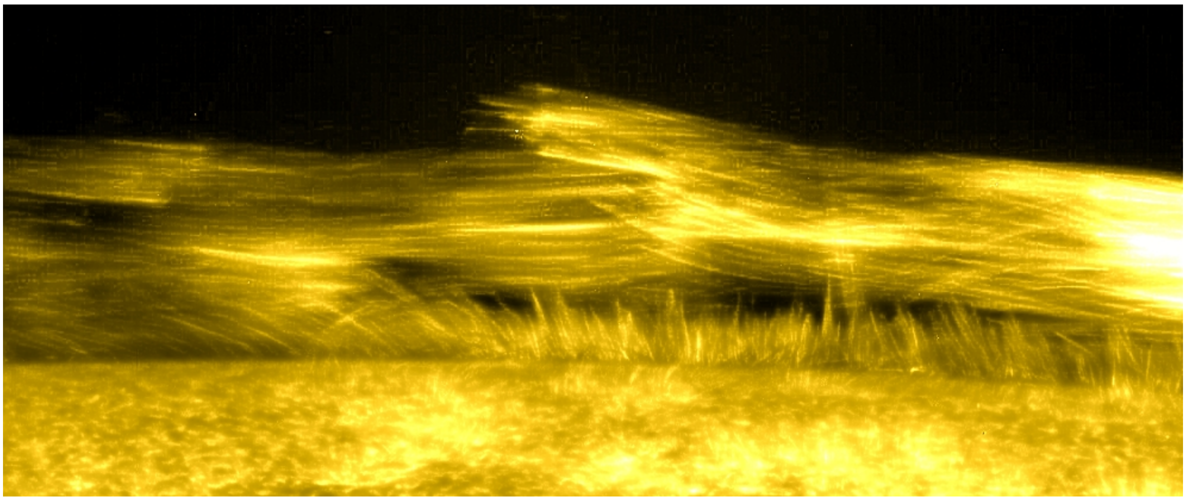
Recent Advances in Solar Partially Ionised Plasma

RAS Discussion Meeting on January 11th 2019 at Burlington House, London



Programme

Time	Speaker and Title	
10:30	Welcome	
10:35	Roberto Soler (I)	Waves and instabilities in the partially ionised solar plasma: an overview
11:15	Jose-Luis Ballester	Effect of heating and cooling processes on the temporal behaviour of MHD waves in a partially ionized prominence plasma
11:32	Istvan Ballai	Waves in partially ionised plasmas in non-equilibrium ionisation
11:49	Ben Snow	Shock substructure in partially-ionised plasma
12:06	Roger Dufresne	Ion Populations in Astrophysical Plasmas: Carbon in the Lower Solar Atmosphere
12:23	Petr Heinzel	Partial ionization of hydrogen plasma in the solar atmosphere - a non-LTE modeler's view
12:40	Lunch hour & Poster Session	
13:40	Elena Khomenko (I)	Modeling of solar partially ionised plasma
14:20	B Kuzma	Heating of the partially-ionized solar chromosphere by 2-fluid acoustic waves
14:37	Beatrice Popescu	Propagation and damping of fast magneto-acoustic shock waves in a stratified atmosphere using the two-fluid approximation
14:54	Ramon Oliver	Dynamics of partially ionised coronal rain
15:11	Manuel Collados	Observational aspects of the solar partially ionised plasma with EST
15:28	Closing comments	
15:30	End	

Invited Talks

Modeling of solar partially ionised plasma

Elena Khomenko (1)

Nikola Vitas (1), Pedro Gonzalez-Morales (1), Paul Cally (2), Manuel Collados (1)
(1) Instituto de Astrofisica de Canarias, Tenerife, Spain
(2) School of Mathematical Sciences, Monash University, Australia

In this contribution we are interested to study the influence of partial ionisation of solar plasma into the energy balance of the solar atmosphere. We will summarize our idealistic non-linear simulations of waves in the partially ionised atmosphere done with Mancha3D code. The emphasis will be done into the generation and dissipation of Alfven waves. In a partially ionised plasma, these waves can be generated through the additional mechanism that couples them to the fast magneto-acoustic waves through the whole photosphere. Their dissipation is produced via the action of the ambipolar effect. The conclusions from idealistic simulations will be checked using realistic 3D radiative-MHD simulations that include battery, ambipolar and Hall effects all together, done again with Mancha3D code. It will be shown that ambipolar diffusion causes measurable effects on the amplitudes of waves excited by convection in the simulations, on the absorption of Poynting flux and heating and on the formation of chromospheric structures. Thanks to the simulations with battery-excited dynamo fields we can provide a low bond on the chromospheric temperature increase due to the ambipolar effect. The Hall effect acts into the direction of significantly increasing the Poynting flux to the upper chromospheric layers, in a rough agreement from what is expected from idealistic wave simulations.

Waves and instabilities in the partially ionised solar plasma: an overview

Roberto Soler (1)

(1) University of the Balearic Islands

Recent observations have shown that MHD waves and instabilities as, e.g., Kelvin-Helmholtz and Rayleigh-Taylor instabilities, are frequent phenomena in the solar atmosphere. The study of waves and instabilities in the solar corona is usually based on ideal MHD theory for a fully ionized plasma. However, the plasma in the photosphere, chromosphere, and prominences is partially or even weakly ionized. In partially ionized plasmas, the interaction between ions and neutrals modifies the behavior and properties of the classic MHD waves and instabilities. In this talk, I will discuss some recent theoretical advances of the study of partial ionization effects on waves and instabilities in the solar atmosphere.

Oral Talks

Waves in partially ionised plasmas in non-equilibrium ionisation

I. Ballai (1)

(1) Plasma Dynamics Group, University of Sheffield

The plasmas ionisation state is a very important factor, as the collision between various components will significantly enhance transport processes that play an important role in the seismological diagnostics of space plasmas and serve as key mechanism in the process of plasma heating.

Research in the dynamical evolution of physical phenomena in the solar atmosphere is based on the assumptions of ionization equilibrium, the equilibrium Maxwellian distribution and elastic collisions between particles. However, this model is not accurate for rapidly changing phenomena, such as high frequency waves. Non-equilibrium ionization can occur during heating or cooling events, significantly affecting line intensities and subsequently the plasma diagnostics. Departures from the equilibrium Maxwellian distribution have been inferred from chromospheric and transition region line emission. In the chromosphere the ionization/recombination times scales are of the order of a few hundred seconds, meaning that dynamics occurring below this scales will be affected by non-equilibrium effects.

The non-equilibrium character of the plasma will be described through the modified number-density and momentum conservation laws, where separate terms will describe the modifications due to the creation and annihilation of ions. The dynamical state of the plasma is investigated within the framework of two-fluid MHD (charged particles and neutrals), with collisions between the massive particles necessary to maintain the system of particles together, however these collisions are inelastic. Given the two-fluid approximation employed here, the spectrum of possible modes is very rich, separate modes will belong to neutrals and ions. The ionisation non-equilibrium is shown to modify the amplitude of waves and the coupling between various modes.

Effect of heating and cooling processes on the temporal behaviour of MHD waves in a partially ionized prominence plasma

J. L. Ballester (1)

M. Carbonel (1), R. Soler (1), J. Terradas (1)

(1) Departament de Física & Institute of Applied Computing & Community Code (IAC3), Universitat Illes Balears

Small amplitude oscillations in prominences are known from long time ago and have been interpreted in terms of standing or propagating linear magnetohydrodynamic (MHD) waves. From a theoretical point of view, these oscillations have been studied by producing small perturbations in a background equilibrium with stationary physical properties. Taking into account that prominences are highly dynamic plasma structures, the assumption of a stationary equilibrium is not realistic, and any imbalance between heating and cooling processes produces a temporal variation of prominences temperature. Then, the degree of ionization of the partially ionized prominence plasma increases/decreases since ionization/recombination takes place and, as a consequence, plasma parameters such as the mean atomic weight, resistivities, viscosity, thermal conduction coefficients, etc. are also modified. Due to the temporal change of the ionization degree, the full expression of the specific internal energy must be considered in our calculations. Furthermore, different optically thin radiation functions as well as thermal conduction by electrons and neutrals have been considered as damping mechanisms, and we have sought for numerical solutions to the linear MHD wave equations when all the abovementioned physical processes are taken into account. In summary, if waves are excited in a non-stationary partially ionized prominence plasma, the changing physical conditions affect wave dynamics by modifying their temporal behaviour, which is of paramount importance for prominence seismology.

Observational aspects of the solar partially ionised plasma with EST

Manuel Collados (1)

(1) Instituto de Astrofisica de Canarias & University of La Laguna

The partial ionisation of the solar atmosphere has been receiving increasing attention in recent years. The presence of neutrals can, for instance, modify the equilibrium of magnetic structures, introduce instabilities under certain magnetic configurations, lead to plasma heating, or change the way the various wave modes transform into each other and propagate through the atmosphere. These are aspects that, in some cases, have been studied in simple scenarios to find analytical expressions that determine the plasma and the field behaviour. More recently, advanced numerical simulations have allowed to gain insight into them with more complex magnetic and plasma configurations. Under an observational point of view, there is little evidence of these phemonena or of the potential decoupling between the neutral and ionised species in some circumstances. With the advent of new large aperture telescopes (EST, DKIST), some of these effects may be observable. In particular, EST has a polarimetrically compensated design which will make possible to detect tiny fluctuations of the magnetic at, both, high spatial resolution and high cadence and may facilitate the identification of the subtle consequences induced by the ions. In this talk, I will discuss the concepts of the new generation instruments of EST and how they can impact the detection of effects related to the partial ionisation.

Ion Populations in Astrophysical Plasmas: Carbon in the Lower Solar Atmosphere

Roger Dufresne (1)

Giulio Del Zanna (1)

(1) Department of Applied Mathematics and Theoretical Physics, University of Cambridge

Higher densities and lower temperatures in the solar chromosphere and transition region mean the most common assumptions used for modelling ion populations in the solar atmosphere (the zero density ionization equilibrium approximation), no longer hold. The presence of metastable levels in the lower charge states will increase the ionization rates once higher densities begin to populate the levels. Burgess and Summers (1969) also showed that the recombination rates reduce as density increases, and the combined effect is to lower the formation temperatures of charge states in these conditions. Using carbon as a test case, new ionization rate calculations for metastable levels have been made and other processes added to calculate the ion charge states. Significant changes with the zero density models are found. Such changes can alter values for plasma parameters derived from ion populations, like temperature, density and elemental abundances. Results from the new ion populations will be presented and compared to solar observations. Modelling the anomalous high intensities of C IV is significantly improved.

Partial ionization of hydrogen plasma in the solar atmosphere - a non-LTE modeler's view

Petr Heinzel (1)

(1) Astronomical Institute, Czech Academy of Sciences

Based on our extensive experience with the non-LTE radiative-transfer modeling of different atmospheric structures (chromosphere, flares, prominences, CME-cores), I will demonstrate the importance of partial hydrogen ionization and review the most relevant atomic processes. I will also discuss the role of non-equilibrium ionization of hydrogen.

Heating of the partially-ionized solar chromosphere by 2-fluid acoustic waves

B. Kuźma (1)

K. Murawski (1)
Maria Curie-Sklodowska University, Lublin, Poland

We investigate the plasma heating resulted from 2-fluid acoustic waves propagating in the gravitationally stratified solar chromosphere. By means of high-resolution 1D simulations we study the behavior of driven high-frequency linear and non-linear waves that originate in the photosphere. We consider ions + electrons and neutrals as separate fluids which interact between their self via collision forces. Due to ion-neutral collisions high-frequency acoustic waves exhibit capability to deposit significant amount of energy in the solar chromosphere.

Dynamics of partially ionised coronal rain

R. Oliver (1,2)

Roberto Soler (1,2), Jaume Terradas (1,2), Teimuraz V. Zaqarashvili (3,4)
(1) Departament de Física, Universitat de les Illes Balears, E-07122 Palma de Mallorca, Spain
(2) Institute of Applied Computing & Community Code (IAC3), UIB, Spain
(3) Institute of Physics, IGAM, University of Graz, Universitatsplatz 5, 8010, Graz, Austria
(4) Abastumani Astrophysical Observatory, Ilia State University, 0162 Tbilisi, Georgia

Coronal rain blobs are dense condensations with chromospheric to transition region temperatures that fall down along coronal loops above active regions. These cold blobs contain a mixture of ionised and neutral material that must be dynamically coupled in order to fall together, as observed. We investigate the coronal rain dynamics by means of 1D hydrodynamic simulations in which the coupling arises from the friction between ions and neutrals. We find that, although the relative drift speed between the two species is smaller than 1 m/s at the blob center, it is sufficient to produce the forces required to strongly couple charged particles and neutrals. The ionisation degree has no discernible effect on the main results of our previous work for a fully ionised plasma: the condensation has an initial acceleration phase followed by a period with roughly constant velocity, and, in addition, the maximum descending speed is clearly correlated with the ratio of initial blob to environment density.

Propagation and damping of fast magneto-acoustic shock waves in a stratified atmosphere using the two-fluid approximation

Beatrice Popescu Braileanu (1,2)

V. S. Lukin (3), E. Khomenko (1,2), Á. de Vicente (1,2)
(1) Instituto de Astrofsica de Canarias, 38205 La Laguna, Tenerife, Spain
(2) Departamento de Astrofsica, Universidad de La Laguna, 38205, La Laguna, Tenerife, Spain
(3) National Science Foundation, Alexandria, VA, 22306, USA

In this study we consider fast magneto-acoustic shock wave formation and propagation in a stratified medium permeated by a horizontal magnetic field, with properties similar to that of the solar chromosphere. The evolution of plasma and neutrals is modeled using a two-fluid code which evolves two independent sets of coupled equations. We observe that waves in neutrals and plasma, initially coupled at the upper photosphere, become uncoupled at higher heights in the chromosphere. This decoupling is either consequences of change of the characteristic spatial scale at the shock front, that becomes similar to the collisional scale, or change of the relation between the wave frequency, ion cyclotron frequency, and the collisional frequency with height. The decoupling height is a sensitive function of the wave frequency and amplitude, and magnetic field strength. We observe that the decoupling causes damping of waves, and increase of the background temperature due to the frictional heating. The comparison between the analytical and the numerical results allows us to separate the role of the non-linear effects from the linear ones on the decoupling and damping of waves.We further study the structure of the shock front using simulations with higher spatial resolution, observing situations similar to C-shocks and J-shocks.

Shock substructure in partially-ionised plasma

Ben Snow (1)

Andrew Hillier (1)
(1) Department of Mathematics, CEMPS, University of Exeter

The partially-ionised nature of the lower solar atmosphere introduces new and exciting complexities to shock solutions. Here we study numerically the slow-mode shock triggered via a magnetic discontinuity, mimicking the slow-mode shocks that can form as a result of magnetic reconnection. In single-fluid ideal MHD, the slow-mode shock occurs as a discontinuous jump in parameters. However, in the two-fluid partially-ionised plasma, the shock occupies a finite width due to the coupling and decoupling of plasma and neutral species across the shock. It is found that this finite width region allows for shock substructure that can affect the overall dynamics of the system. In particular, we find that under certain parameter regimes, an intermediate shock can exist where the plasma velocity transitions from super to sub Alfvenic velocities. A key feature of this type of shock is that the magnetic field is reversed across the interface. We present numerical results analysing the formation conditions of intermediate shocks as substructure within slow-mode shocks, and the resultant consequences.

Posters

Alfven Waves in a partially ionized two-fluid plasma

Marc Carbonell (1)

José luis Ballester (1), Jaume Terradas (1)
(1) Dpt Matemàtiques i Informàtica, Universitat de les Illes Balears

We study Alfven waves in a partially ionized plasma from the theoretical point of view using the two-fluid description. We consider the plasma is composed of an ionelectron fluid and a neutral fluid, interacting by particle collisions. We take the neutralion collision frequency and the ionization degree as free parameters. First, we perform a normal mode analysis. We find the modification due to neutralion collisions of the wave frequencies and study the temporal and spatial attenuation of the waves. In addition, we discuss the presence of cutoff values of the wavelength that constrain the existence of oscillatory standing waves in weakly ionized plasmas. Later, we go beyond the normal mode approach and solve the initial-value problem in order to study the time-dependent evolution of the wave perturbations in the two fluids. An application to Alfven waves in the low solar atmospheric plasma is performed and the implication of partial ionization for the energy flux is discussed.

Understanding the Role of Mass within Prominence Eruptions

Jack Jenkins (1)

Matthew Hopwood (2,3), Gherardo Valori (1), Pascal Demoulin (4), Guillaume Aulanier (4), Jack Carlyle (5), David Long (1), Lidia van Driel-Gesztelyi (1,4,6)
(1) Mullard Space Science Laboratory, University College London
(2) University of Birmingham
(3) University of Adelaide
(4) LESIA - Observatoire de Paris
(5) ESTEC, Netherlands (Formerly)
(6) Konkoly Observatory of the Hungarian Academy of Sciences

We combine observations of a partial prominence eruption on 11 December 2011 with a simple line current model to demonstrate that including mass is an important next step for understanding solar eruptions. Observations from the Solar Terrestrial Relations Observatory-Behind (STEREO-B) and the Solar Dynamics Observatory (SDO) spacecraft were used to remove line-of-sight projection effects in prominence motion. The two viewpoints enable the amount of mass drained to be estimated, and an investigation of the subsequent radial expansion and eruption of the prominence. We use these observational measurements, alongside synthetic inputs, to constrain a line current model and quantitatively demonstrate the important role that the presence and draining of mass has in the lead-up to solar eruptions. Specifically, for a line current suspended within a bipolar background potential magnetic field generated by a source field of 4 G, we first show that the inclusion of realistic prominence mass can increase the height of the critical decay index by up to 14%. We then show that the balance of magnetic and gravitational forces acting on the line current is increasingly sensitive to mass perturbations as it approaches its loss-of-equilibrium; mass-draining can increase the height of the prominence without upper bound, so leading to an eruption. However, scaling the surface field up to active region strengths shows that the role of mass is negligible under such conditions. Finally, we conclude that the role of mass within prominence eruptions, particularly those rooted within the quiet-Sun, is greater than has been historically attributed and requires more study.

Magnetic Kelvin-Helmholtz instability in a partially ionised plasma

Andrew Hillier (1)
(1) CEMPS, University of Exeter

Resistive Dissipation of Alfvén Waves in the Corona

Jeffrey Reep (1)
Alexander Russell (2), Graham Kerr (3)
(1) NRL
(2) University of Dundee
(3) NASA GSFC

Reconnection events in the corona drive the generation Alfven waves, which can then transport significant amounts of energy through the atmosphere. The dissipation of these waves produces heating in both the chromosphere and corona, which has been mostly overlooked in the literature of both flares and nanoflares. I will describe a new hydrodynamic model we have developed to study the resistive dissipation of these waves, which has been validated against an MHD model. I will show that the dissipation of these waves leads to unique observational signatures, such as a propagating ionization front in the chromosphere, which may be detected by future instruments with both high cadence and spatial resolution. I will then give an overview of when wave heating is significant and when it is negligible, in terms of Poynting fluxes, perpendicular wave numbers, frequencies, and magnetic field strengths. Finally, using a forward model, I will show high cadence profiles of spectral lines as might be observed by IRIS, EIS, and potentially EUVST.