Workshop on Partially Ionized Plasmas in Astrophysics

Tenerife, June 19-22, 2012

Abstracts, sorted by day & session

TUESDAY JUNE 19TH

Session 1: Equations and numerical methods

Presenting author: **KHOMENKO, ELENA**
Contributing authors: Collados, M, Díaz, A.
Title: OVERVIEW OF EQUATIONS & ASSUMPTIONS

Abstract: The particular temperature and density conditions in the magnetized photosphere and chromosphere of the Sun usually lead to a very small degree of atomic ionization. In addition, at particular heights, the magnetic field may be strong enough to give rise to a cyclotron frequency larger than the collisional frequency for some species, while for others the opposite may happen. These circumstances can influence the collective behaviour of the particles and some of the hypotheses of MHD may be relaxed, giving rise to non-ideal MHD effects. These effects are potentially important for the dynamics and energy exchange in the solar photosphere and, especially, chromosphere. In particular, there are evidences that such phenomena as wave propagation and damping, magnetic reconnection, formation of stable magnetic field concentrations, magnetic flux emergence, etc. can be affected. In this contribution, I will discuss the different ways of treating the multi-component solar plasma and revise the assumptions and derivation of the single-fluid (quasi-MHD) and two-fluid equations, as well as the generalized Ohm´s low. I will discuss the importance the different terms of the generalized Ohm's low may have for different solar situations.

Presenting author: **ZAQARASHVILI, TEIMURAZ**
Contributing authors: Khodachenko, M.
Title: TWO-FLUID APPROACH FOR PARTIALLY IONIZED SOLAR PLASMAS

Abstract: Partially ionized plasma is usually described by a single-fluid approach, where the ion-neutral collision effects are expressed by Cowling conductivity in the induction equation. However, the single-fluid approach is not valid for time-scales less than ion-neutral collision time. For these time-scales the multi-fluid description is the better approximation. We start from the fluid equations for each species, which are derived from Boltzmann kinetic equations. Then we obtain two-fluid MHD equations, where ion-electron plasma and neutral particles are considered as separate fluids. We derive the dynamics of magnetohydrodynamic waves in two-fluid partially ionized solar plasmas and compare the results with those obtained under single-fluid description.

Presenting author: **DÍAZ, ANTONIO**
Contributing authors:
Title: **COLLISIONAL FREQUENCIES, PRESSURE TENSOR AND PLASMA DRIFTS**

Abstract: We review some open question in plasma physics applied to the Sun. The closure problem is introduced, as well as the particle drifts and its relation with the anysotropic pressure tensor. The transport coefficients are also discussed, as well as the different approaches to reinder the multi-fluid theory operational, with a mention to the collisional frequencies and their relevance in the different models.

Presenting author: **VRANJES, JOVO**
Contributing authors:
Title: STOCHASTIC HEATING IN NON-EQUILIBRIUM PLASMAS

Abstract: Most of electrostatic modes within the multi-component plasma theory may be used for plasma heating. The heating is stochastic by nature and it requires large enough electric field associated with the wave, yet it is still completely linear phenomenon. In space, such wave electric fields may develop only providing some energy source. Plasmas which are not in thermodynamic equilibrium have free energy that may be released by developing instabilities, producing electric fields that further heat the plasma. In this talk, the instabilities of the ion acoustic and the drift (oblique and transverse) waves will be presented driven by two different sources of energy, that is by plasma inhomogeneity and flows. The instabilities are either collisional (described within the fluid theory) or purely kinetic and collisionless. Details of stochastic particle motion in the wave field and properties of stochastic heating will be presented and its application to the solar atmosphere will be discussed.

Presenting author: **FALLE, SAM**
Contributing authors:
Title: NUMERICAL SCHEMES FOR MULTIFLUID MAGNETOHYDRODYNAMICS

Abstract: In star forming regions, the fractional ionization can be very small and charged dust particle can therefore make a significant contribution to the current. It is possible to model this by assuming that there are two fluids, a neutral fluid and a perfectly conducting fluid that interact via a friction term. However, schemes based on this are very inefficient when the density of the conducting fluid is small compared to that of the neutral fluid. They are also unable to handle dust particles that are not closely tied to the field lines. However, the low ionization fraction means that the inertia of the charged particles can be neglected, in which case the magnetic diffusion is described a generalised Ohm's law. One can then construct efficient schemes that solve this equation implicitly or use super time stepping. This talk will describe such schemes together with some applications.

Presenting author: **VITAS, NIKOLA**
Contributing authors:
Title: RADIATIVE TRANSFER IN MULTI-FLUID AND MHD SIMULATIONS

Abstract: Structure and dynamics of the solar atmosphere are driven by the energy exchange between radiation and matter. In the energy conservation equation of the multi-fluid plasma that exchange is quantified through the radiative heating rate which is defined by the solution of the radiative transfer equation (RTE). Solving that equation accurately and efficiently is thus a critical requirement for realistic simulations of the solar photosphere and chromosphere. Here we review some of the commonly used RTE solvers in the context of their applicability to the new multi-fluid code that is developed within the SPIA project. We consider their performance for different angle and frequency discretizations and computation grids.

Presenting author: **LEENAARTS, JORRIT**
Contributing authors:
Title: NON-EQUILIBRIUM IONIZATION OF HYDROGEN AND HELIUM IN THE SOLAR ATMOSPHERE

Abstract: : Hydrogen ionization in the solar chromosphere and transition region is out of instantaneous statistical equilibrium, which affects the pressure, temperature, electron density and has a profound effect on the heating through neutral-ion drag. I will discuss these effects and explain how to incorporate non-equilibrium ionization physics for hydrogen in an MHD code. I will argue a similar treatment is required for helium.

WEDNESDAY JUNE 20TH

Session 2: Formation of stable structures and instabilities

Presenting author: **ARBER, TONY**
Contributing authors**:**
Title: PEDERSON RESISTIVITY IN THE CHROMOSPHERE

Abstract: Review recent work on flux emergence and equilibrium structures in the chromopshere and how they are affected by the Pederson resistivity. Particular attention will be given to simplified models of the ionisation fraction which can be used quickly in fluid models.

Presenting author**: DÍAZ, ANTONIO**
Contributing authors: Soler, R., Ballester, J. L., Khomenko, E., Collados, M., de Vicente, A.
Title: **RAYLEIGH – TAYLOR INSTABILITY IN PROMINENCES**

Abstract: We study the modification of the classical criterion for the linear onset and growing rate of the Rayleigh-Taylor instability (RTI) in a partially ionized plasma in the one-fluid description, considering a generalized induction equation, and then in a two-fluid description of plasma composed of a neutral fluid and an electron-ion fluid, coupled by means of particle collisions. The governing linear equations and appropriate boundary conditions, including gravitational terms, are derived and applied to the case of the RTI in a single interface between two partially ionized plasmas. The results from the linear analysis are then checked with the help of numerical computations of the RTI. The configuration is always linearly unstable when a lighter plasma is below a heavier plasma regardless the value of the magnetic field strength, the ionization degree and the ion-neutral collision frequency. However, ion-neutral collisions have a strong impact on the RTI growth rate, which can be decreased by an order of magnitude compared to the value in the collisionless case. Hence, ion-neutral collisions are necessary to accurately describe the evolution of the RTI in partially ionized plasmas such as prominences, since the time scales derived from the classical theory are about one order o f magnitude shorter and incompatible with the observed life times.

Presenting author**: GILBERT, HOLLY**
Contributing authors**:**
Title: NEUTRAL ATOM DIFFUSION IN A PARTIALLY IONIZED PROMINENCE PLASMA

Abstract: The support of solar prominences is normally described in terms of a magnetic force on the prominence plasma that balances the solar gravitational force. Because the prominence plasma is only partially ionized, it is necessary to consider in addition the support of the neutral component of the prominence plasma. This support is accomplished through a frictional interaction between the neutral and ionized components of the plasma, and its efficacy depends strongly on the degree of ionization of the plasma. More specifically, the frictional force is proportional to the relative flow of neutral and ion species, and for a sufficiently weakly ionized plasma, this flow must be relatively large to produce a frictional force that balances gravity. A large relative flow, of course, implies significant draining of neutral particles from the prominence. We evaluate the importance of this draining effect for a hydrogen-helium plasma, and consider the observational evidence for cross-field diffusion of neutral prominence material.

Presenting author: **DOWNES, TURLOUGH P.**
Contributing authors**:**
Title: **THE KELVIN-HELMHOLTZ INSTABILITY IN WEAKLY IONISED FLOWS**

Abstract: We present a study of the Kelvin-Helmholtz instability in a weakly ionised, multifluid MHD plasma with parameters matching those of a typical molecular cloud. Since these clouds are weakly ionised, the ideal magnetohydrodynamic approximation does not apply at scales of around a tenth of a parsec or less. The effects of ambipolar diffusion and the Hall effect are studied together using physical parameters applicable to molecular clouds. We find that while the introduction of multifluid effects does not affect the linear growth rates of the instability, the non-linear behaviour undergoes considerable change.

Presenting author: **BALLESTER, JOSE LUIS**
Contributing authors**:** Soler, R., Parenti, S., Goossens, M.
Title: THERMAL INSTABILITY IN FULLY AND PARTIALLY IONIZED PROMINENCE PLASMAS

Abstract: Prominences/Filaments are often considered as fully ionized plasmas. However, at least the cool plasma usually observed in Hα is partially ionized. Partial ionization produces additional effects when MHD waves and Instabilities are considered. Here, I will report on recent research done on Thermal Instability in fully and partially ionized prominence plasmas as a potential mechanism able to explain filament threads short lifetime.

Presenting author**: OLIVER, RAMON**
Contributing authors**:**
Title: DOWNFLOWING DYNAMICS OF VERTICAL PROMINENCE THREADS

Abstract: Vertical threads are common features of solar prominences and their dynamics can be observed in unprecedented detail with new solar telescopes. In particular, it has been seen that material falling along these threads moves with an acceleration smaller than that of free-fall. A simple model of a partially ionised plasma is used to investigate these vertical downflows. For a fully ionised gas it is found that gas and magnetic pressure gradients setup and strongly reduce the effect of solar gravity. The magnetic pressure gradient has the most important effect because it greatly increases the vertical scale height. The neutral fraction of the gas behaves like a fully ionised gas, but it undergoes collisional coupling with the ionised component. For this reason a partially ionised gas also falls with smaller than free-fall acceleration, although faster than its fully ionised counterpart.

WEDNESDAY JUNE 20TH
Session 3: Non-solar astrophysical plasmas

Presenting author: **DOWNES, TURLOUGH P.**
Contributing authors**:**
Title: **MULTIFLUID MHD TURBULENCE IN MOLECULAR CLOUDS**

Abstract: It is believed that turbulence may have a significant impact on star formation and the dynamics and evolution of the molecular clouds in which this occurs. It is also known that non-ideal magnetohydrodynamic effects influence the nature of this turbulence. We present the results of a numerical study of 4-fluid MHD turbulence in which the dynamics of electrons, ions, charged dust grains and neutrals and their interactions are followed. The parameters describing the fluid being simulated are based directly on observations of molecular clouds. We find that the velocity and magnetic field power spectra are strongly influenced by multifluid effects on length-scales at least as large as 0.05 pc. The PDFs of the various species in the system are all found to be close to log-normal, with charged species having a slightly less platykurtic (flattened) distribution than the neutrals. We find that the introduction of multifluid effects does not significantly alter the structure functions of the centroid velocity increment.

Presenting author**: FALLE, SAM**
Contributing authors**:**
Title: NUMERICAL SIMULATIONS OF THE WARDLE INSTABILITY

Abstract: In dense interstellar clouds, the ionisation fraction is so low that the material may be considered to be made up of two fluids: a perfectly conducting fluid consisting of the ions and electrons and a neutral fluid consisting of atomic hydrogen. These interact via collisions, but the imperfect coupling leads to a finite resistivity, which is usually called ambi-polar diffusion. Under these conditions, there exist shock structures, called C-shocks, in which the dissipation is due to resistivity rather than viscosity (Draine 1980). Since the thickness of such shocks is several orders of magnitude greater than that of a viscous shock, it is possible for the gas to remain cold, which in turn permits the survival of molecules that would be destroyed by the heating in a viscous shock.
Wardle (1990, 1991a,b) showed that C-shocks with Alfven Mach numbers greater than ~ 5 are subject to a transverse corrugation instability and nonlinear calculations have shown that this leads to the formation of dense fingers of neutral gas (Toth 1995a,b; Neufeld & Stone 1997; MacLow & Smith 1997). This has several consequences: the emission from an unstable shock is very different from that of a steady shock; the shock transition may no longer be smooth enough to prevent the destruction of molecules; the instability might play a role in the generation of the observed density inhomogeneities in dense clouds.
However, the instability relies on a separation between the conducting fluid and the neutral fluid, which does not occur if timescale for ionisation equilibrium is short compared to the flow time through the shock structure. The ionisation fraction is then simply a function of neutral density and our simulations show that this does indeed suppress the instability. Since the timescale for ionization equilibrium is always short compared to the flow time in dense clouds, this means that the instability does not occur unless charged grains play a significant role. Instability is possible in this case because a fluid composed of charged grains does undergo separation from the neutrals and the grain mass fraction influences the ionization fraction. We use the multi-fluid code described in Falle (2003), which includes the grain fluid, to show that the instability can occur in such cases.

Presenting author: **KHODACHENKO, MAXIM**
Contributing authors:
Title: MAGNETOSPHERES OF "HOT JUPITERS"

Abstract: The constantly growing number of discovered exoplanets and accumulation of data regarding their physical and orbital characteristics provide an empirical platform for a more detailed study of general principles and major trends of the planetary evolution (including the planetary potential habitability aspect). More than a half of known exoplantes have orbits around their host stars shorter than 0.6 AU. By this, a clear maximum in the orbital distribution of exoplanets takes place in the vicinity of 0.05 AU. A close location of planets to their host stars means that they are exposed to intensive stellar radiations and plasma flows, which are stronger near a star. Majority of these close-orbit exoplanets belong to the class of giant planets and are called therefore as "Hot Jupiters". Hydrodynamic expansion of an exoplanetary upper atmosphere, heated by stellar XUV, with the consequent photo-ionization of the expanding atmospheric gas leads to the formation of an extended, essentially dynamical planetary ionosphere/magnetosphere. Of crucial importance in that respect appears formation of plasma magnetodisks around the close-orbit exoplanets resulted from the planetary rotation and hydrodynamic escape of the partially ionized upper atmospheric material. The interaction of these expanding planetary partially ionized plasma envelopes with the intrinsic planetary magnetic fields and the stellar winds, as well as creation of magnetodisks, lead to the development of a new type of magnetospheres, not typical for the solar system planets. So far, a self-consistent description for the interaction of an expanding partially ionized plasmosphere of an exoplanet with the intrinsic planetary magnetic field has not been made. Existing studies either formally address the problem without its detailed treatment, or completely ignore the whole complex of the physical effects related with the plasma partial ionization. Correct and self-consistent modelling of these processes in the expanding magnetized and partially ionized plasmospheres of close-orbit exoplanets and their contribution to the shaping of the exoplanetary magnetospheres, requires further theoretical study and development of efficient methodological approaches. The presentation will outline several basic issues regarding that investigation.

Presenting author: **OLSHEVSKY, VYACHESLAV**
Contributing authors: Restante, A. L., Lapenta, G., Keppens, R.
Title: COUPLING SOLAR SIMULATIONS WITH SPACE WEATHER: CODE COMPARISON WITHIN SWIFF CONSORTIUM

Abstract: During the first year of Space Weather Integrated Forecasting Framework (SWIFF) project, the comparison of different numerical codes was performed on a number of benchmark problems. We report the results of the three-dimensional simulations of a rising magnetic flux rope, performed with two MHD codes: FlipMHD and MPI-AMRVAC. The results obtained by the two codes with the same parameters are qualitatively the same. However, the flux rope rises slower in the simulations made with FlipMHD. We propose this setup as a benchmark problem for comparison of numerical codes used in solar simulations.

THURSDAY JUNE 21ST

Session 4: Waves

Presenting author: **BALLESTER, JOSE LUIS**
Contributing authors: Zaqarashvili, T., Carbonell, M., Khodachenko, M.
Title: **CUT-OFF WAVENUMBER IN SINGLE-FLUID MHD**

Abstract: Alfvén (fast) wave dynamics in resistive single-fluid magnetohydrodynamics shows the presence of cut-off wavenumber i.e. Alfvén (fast) waves with wavenumbers higher than the cut-off value are evanescent. The cut-off wavenumber appears in both, fully and partially ionized plasmas. To point out the reason for the appearance of a cut-off wavenumber, we start with three-fluid equations (with electrons, protons and neutral hydrogen atoms) and make consecutive approximations until the usual single-fluid description is obtained. We solve the dispersion relation of linear Alfvén waves at each step and seek for the approximation responsible of the cut-off wavenumber appearance. The cut-off wavenumber in single-fluid MHD is the result of neglecting the inertial and Hall terms.

Presenting author: **KHODACHENKO, MAXIM**
Contributing authors:
Title: DAMPING OF MHD WAVES IN PARTIALLY IONIZED PLASMAS

Abstract: Magnetohydrodynamic (MHD) waves are widely considered as a possible source of heating for various parts of the outer solar atmosphere. Among the main energy dissipation mechanisms which convert the energy of damped MHD waves into thermal energy are collisional dissipation (resistivity), viscosity, and thermal conductivity. The presence of neutral atoms in the partially ionized plasmas of the solar photosphere, chromosphere and prominences enhances the efficiency of these energy dissipation mechanisms. A comparative study of the efficiency of MHD wave damping in solar plasmas due to collisional, viscous, and thermal conductivity energy dissipation mechanisms is presented. All the important solar MHD modes, e.g., Alfven wave, fast magnetoacoustic wave and slow magnetoacoustic/acoustic wave, are considered. The estimation of damping rates follows the way proposed in Braginskii (1965) and is then applied to the case of VAL C model of the quiet Sun (Vernazza et al. 1981). While the frictional dissipation (electrical resistivity) can usually be safely neglected as compared to the viscosity and thermal conductivity effects in the fully ionized solar corona, the relation and mutual role of all the dissipation mechanisms for the damping of different types of MHD waves in the lower (partially ionized) solar atmosphere and in prominences requires a special comparative study. We give some basic comparative estimations concerning damping of MHD waves in the solar plasmas which may be used to decide which dissipation mechanism and where can be considered as a dominating one, as well as define the cases where several damping mechanisms should be taken into account.

Presenting author: **SOLER, ROBERTO**
Contributing authors:
Title: RESONANT DAMPING OF PROMINENCE THREAD OSCILLATIONS: EFFECT OF PARTIAL IONIZATION

Abstract: The fine structures of solar prominences, here called threads, often display transverse oscillations. A typical feature of these oscillations is that they are quickly damped in few periods. The oscillations have been theoretically interpreted as Alfvenic kink waves. Resonant absorption, caused by plasma inhomogeneity in the transverse direction to the magnetic field, has been suggested as the damping mechanism. The resonant damping of Alfvenic waves has been investigated in fully ionized plasmas. However, due to their relatively cool temperature, prominence plasmas are only partially ionized. Here we investigate the impact of partial ionization on the resonant damping of Alfvenic kink waves in prominence threads. We do so by following two different approaches. First, we use the single-fluid approximation in which the effect of ion-neutral collisions is represented by Cowling's diffusion term in the generalized induction equation. We find that Alfvenic kink waves are damped by both resonant absorption and Cowling's diffusion. The contribution of resonant absorption to the damping is inversely proportional to the frequency as in the fully ionized case, while the contribution of Cowling's diffusion is inversely proportional to the square of the frequency. For wave frequencies typically observed in prominences the effect of resonant absorption dominates. Later, we extend this investigation by using the two-fluid approach in which ions and electrons are considered together as an ion-electron fluid, i.e., the plasma, while neutrals form another fluid that interacts with the plasma by means of collisions. The collision frequency is taken as an arbitrary parameter and, as expected, we recover the single-fluid results in the limit of high collision frequencies. We conclude that ion-neutral collision damping is always less efficient than resonant damping unless the wave frequency and the collision frequency are of the same order.

Presenting author: **ZAQARASHVILI, TEIMURAZ**
Contributing authors: Khodachenko, M.
Title: DAMPING OF ALFVÉN WAVES IN SOLAR PARTIALLY IONIZED PLASMAS: EFFECT OF NEUTRAL HELIUM IN A MULTI-FLUID APPROACH

Abstract: Chromospheric and prominence plasmas contain neutral atoms, which may change the plasma dynamics through collision with ions. Most of the atoms are neutral hydrogen, but a significant amount of neutral helium may also be present in the plasma with a particular temperature. Damping of MHD waves due to ion collision with neutral hydrogen has been studied well, but the effects of neutral helium are largely unknown. We aim to study the effect of neutral helium in the damping of Alfven waves in solar, partially ionized plasmas. We consider a three-fluid magnetohydrodynamic (MHD) approximation, where one component is electron-proton-singly ionized helium and the other two components are the neutral hydrogen and neutral helium atoms. We derive the dispersion relation of linear Alfven waves in isothermal and homogeneous plasma. Then we solve the dispersion relation and derive the damping rates of Alfven waves for different plasma parameters. The presence of neutral helium significantly enhances the damping of Alfven waves compared to the damping due to neutral hydrogen at certain values of plasma temperature (10000-40000 K) and ionization. Damping rates have a peak near the ion-neutral collision frequency, but decrease for the higher part of the wave spectrum. The collision of ions with neutral helium atoms can be important for the damping of Alfven waves in chromospheric spicules and in prominence-corona transition regions.

Presenting author: **VERTH, GARY**
Contributing authors:
Title: IONISATION DIAGNOSTICS OF SOLAR MAGNETIC STRUCTURES

Abstract: Spicules have recently been the subject of much renewed interest for being conduits of significant wave energy and the possible source of coronal temperature plasma. However, due to their fine structure and temporal variability they still remain very difficult objects to study and understand. Traditionally, the height dependent ionization fraction in the solar chromosphere has been estimated using atomic models in conjunction with spectroscopic data for average quiet Sun conditions. How due we try and quantify the ionization fraction along such dynamic and fine scale spicule structures? In this talk, I describe the main challenges and suggest that a two pronged approach of using traditional spectroscopic methods alongside more recent magnetoseismological studies of observed spicule wave properties can provide a way forward.

THURSDAY JUNE 21ST

Session 5: Numerical simulations

Presenting author: **CAMERON, ROBERT**
Contributing authors: Cheung, M.
Title: **MAGNETOHYDRODYNAMICS OF THE PARTIALLY-IONIZED SOLAR ATMOSPHERE**

Abstract: We discuss some of the effects of Hall currents and ambipolar diffusion on the dynamics and structuring of the lower solar atmosphere.

Presenting author**: KHOMENKO ELENA**
Contributing authors**:** Collados, M., Vitas, N.
Title: CHROMOSPHERIC HEATING BY AMBIPOLAR DIFFUSION

Abstract: We propose a mechanism for efficient heating of the solar chromosphere, based on non-ideal plasma effects. Three ingredients are needed for the work of this mechanism: (1) presence of neutral atoms; (2) presence of a non-potential magnetic field; (3) decrease of the collisional coupling of the plasma. Due to decrease of collisional coupling, a net relative motion appears between the neutral and ionized components, usually referred to as ``ambipolar diffusion". This results in a significant enhancement of current dissipation as compared to the classical MHD case. We propose that the current dissipation in this situation is able to provide enough energy to heat the chromosphere by several kK on the time scale of minutes, or even seconds. In this paper, we show that this energy supply might be sufficient to balance the radiative energy losses of the chromosphere. We include simulations with non-grey radiative transfer effects taking into account.

Presenting author**: MARTINEZ-SYKORA, JUAN**
Contributing authors**:**
Title: NUMERICAL SIMULATIONS INCLUDING AMBIPOLAR DIFFUSION

Abstract: The bulk of the solar chromosphere is weakly ionized and interactions between ionized particles and neutral particles will have significant consequences for the thermodynamics of the chromospheric plasma. We investigate the importance of introducing neutral particles into the MHD equations using numerical 2.5D radiative MHD simulations obtained with the Bifrost code. The models span the solar atmosphere from upper layers of the convection zone to the low corona, and solve the full MHD equations with non-grey and non-LTE radiative transfer and thermal conduction along the magnetic field. The effects of partial ionization are implemented using the generalized Ohm's law, i.e., we consider the effects of the Hall term and Pedersen dissipation in the induction equation. We find that in the chromosphere, the Pedersen dissipation is of the same order of magnitude or even larger than the numerical diffusion used to stabilize our code. As result of this, we can study the eff ects of it in the simulations. The Pedersen dissipation produces strong impact on the chromosphere changing the thermal properties, dynamics and magnetic field evolution.

Presenting author: **WEDEMEYER-BOHM, SVEN**
Contributing authors:
Title: NON-EQUILIBRIUM CALCIUM IONISATION IN THE SOLAR ATMOSPHERE

Abstract: The assumption of ionisation equilibrium is reviewed for the quiet solar chromosphere by means of 1-D numerical simulations with the RADYN code. It combines hydrodynamics with a detailed solution of the radiative transfer equation, including a non-equilibrium treatment of hydrogen, calcium, and helium. The simulations are characterised by strong temperature fluctuations and variations of the ionisation degree of calcium, which are caused by upwards propagating shock waves. The passage of a hot shock front leads to a strong net ionisation of Ca II, which is rapidly followed by net recombination. The relaxation timescale of the Ca ionisation state is typically between a few seconds and one minute with extreme values of up to ∼150 s. The timescales are dominated by radiative transitions that depend strongly on the density of free electrons and therefore on the ionisation degree of hydrogen. The resulting ionisation/recombination timescales are therefore too long for the assumption of instantaneous ionisation equilibrium to be valid and, on the other hand, are not long enough for the assumption of a constant ionisation fraction. The detailed treatment of Ca ionisation has however only negligible impact on the modelling of the chromospheric plasma properties and the formation of Ca II spectral lines since the Ca II ionization degree remains small in the chromosphere.

Presenting author: **DE PONTIEU, BART**
Contributing authors: Martinez-Sykora, J., Hansteen, V., Pereira, T., Carlsson, M.
Title: ALFVEN WAVES, SPICULES AND THE PARTIALLY IONIZED CHROMOSPHERE

Abstract: Effects from the large neutral population in the partially ionized chromosphere are expected to be significant, from damping of Alfven waves, formation of spicules, to significant heating of the chromosphere. I will briefly describe recent numerical modeling using the advanced 3D radiative MHD simulations (including the generalized Ohm's law) with the Bifrost code that highlight the large impact of dynamics in a realistic chromosphere on estimates of various resisitivities. The ohmic diffusion, Hall term, and Pedersen diffusivities show variations of several orders of magnitude in the chromosphere. These strong variations of the various magnetic diffusivities are absent and significantly underestimated when using the semi-empirical VAL-C model as a basis for estimates. I will also show recent analysis of the dynamical properties of type II spicules that provide strict constraints on spicule formation models. A crucial aspect of these constraints is that our recent observations show unequivocal evidence for strong torsional Alfven waves in all type II spicules.

FRIDAY JUNE 22ND
Session 6: Solar phenomena

Presenting author: **HANSTEEN, VIGGO**
Contributing authors:
Title: MODELING THE SOLAR CHROMOSPHERE

Abstract: A number of increasingly sophisticated numerical simulations have shed considerable light on the workings of the solar chromosphere. This includes the importance of the magnetic field and the interplay between waves and the structure of the chromospheric plasma. Complementing the numerical models, high cadence temporal and high resolution spatial observations, both space based and on the ground, are changing and challenging previously held views. In this talk we will discuss the interplay between simulations and observations: how the simulations can aid interpretation of the observations and how observations help improve the physics present in the models.

Presenting author: **ERDELYI, ROBERT**
Contributing authors:
Title: ION-NEUTRAL DAMPING SPICULE FORMATION AND ELLERMAN BOMBS

Abstract: The latest satellite and ground-based observations have provided a wealth of evidence of small-scale evens present in the solar atmosphere. Our understanding of the structure and dynamics of the magnetised solar atmosphere has been considerably changed in light of the high spatial and time resolution observations (e.g. DST/ROSA, IBIS, CoMP, STT/CRISP; SOHO, TRACE, STEREO, Hinode, SDO, etc.) allowing us to perform sub-resolution studies of MHD waveguides. One such intriguing waveguide is the solar spicules. I will discuss some controversial issues related to spicule formation, how they may act as waveguides, what oscillations may propagate along them and how ion-neutral damping may (not) be relevant in their dynamics with impact on atmospheric heating. I will also relate the spicule phenomenon to Ellerman bombs abundantly observed in the lower solar atmosphere using cutting-edge instrumentation (e.g. ROSA mounted at DST, Sac Peack) and discuss the presence of MHD waves in these structures.

Presenting author: **COLLADOS, MANUEL**
Contributing authors: Khomenko, E., Díaz, A.
Title: **BEHAVIOUR OF NEUTRAL AND IONIZED IRON IN SUNSPOTS**

Abstract: We present the results of an observational analysis aimed at studying the potential differences in the behaviour of neutral and ionized atoms. The motion of these two species may be decoupled if the cyclotron frequencies induced in ions by strong magnetic fields, such as those of sunspots, are large enough to exceed the collisional frequencies between species. The low ionization degree (<1e-4) existing in the photosphere and low chromosphere may also give rise to significant deviations from the collective behaviour of the different species composing the plasma. In this work, velocity maps of sunspots have been obtained in wavelength intervals including neutral and ionized iron spectral lines formed at similar heights. Their comparison and height dependence may give clues to understand potential deviations from the ideal magnetohydrodynamics governing a fully-ionized perfectly-conducting plasma.
