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P. Di Matteo, F. Billebaud, F. Herpin, N. Lagarde, J.-B. Marquette, A. Robin, O. Venot (eds)

THE MULTI FLUID DESCRIPTION OF THE CHROMOSPHERIC MOTIONS

A. Tkachenko[1], S. Shelyag[2], V. Krasnosselskikh[1] and L. Le Phuong[2]

Abstract. The major diagnostics of solar chromosphere comes from spectroscopic observations of different spectral lines, which provide the information about the dynamics of minor ions, using strong lines, associated with them (observed by SOHO, SDO, IRIS etc.). They indicate the variation of temperature with altitude and time. On the other hand, general dynamics of the chromosphere is determined by three main components: electrons, protons and neutral hydrogen atoms (probably sometimes by helium component also). We consider the model, similar to plasma discharge, describing it by the system of three-fluid hydrodynamic equations for partially ionized plasma in the presence of electric and magnetic fields. Our description accounts for the processes of ionization and recombination as well as the dissipation of electric currents. Minor ions and atoms are included into our description as impurities, diffusing in the dominant components gas. Ionization of minor ions is supposed to happen due to collisions with electrons. To achieve this goal, we have the numerical code, written by Sergiy Shelyag and Linh Le Phuong, which is a multi-dimensional parallel solver of systems of hyperbolic differential equations on an arbitrary Cartesian grid. It has already been configured to solve the systems of hydrodynamic, magneto-hydrodynamic and two-fluid magneto-hydrodynamic (ions + neutrals) equations. The code takes into account ionization, recombination and collisional processes for non-linear simulations of solar partially- and fully-ionized plasmas. Actually we are going to test different properties of the code.

Keywords: chromosphere, multi-fluid, corona, heating

1 Introduction

The main problems of coronal physics are the coronal heating and the acceleration of the solar wind. Existing models of these phenomena are based on magnetic field line reconnection, wave heating and velocity filtration. These models consider the corona, while the chromosphere can determine the processes, which drive the physical phenomenon, taking place in coronal region. VAL-C models for Quiet Sun demonstrate, that collision rates remain high in chromospheric region. Moreover, the ionization rate of gas remains very low, up to the beginning of TR. Reconnection models are not applicable to this region. The ideal MHD models consider fully ionized media, and, consequently, do not take into account important features, which take their origins from the chromosphere. As an example, the analysis of the simulation by Abbett et al., near temperature minimum region shows, that $\overrightarrow{V} \times \overrightarrow{B}$ results the enormously high electric field (Abbett et al. 2004), (Abbett 2007). With finite conductivity physical processes are very far from ideal MHD description.

2 Our model

2.1 *What should be added?*

Dynamics of the chromosphere is determined by ions, neutrals and electrons. The effects of ionization and recombination should be properly described. Observations and remote sensing of chromosphere by means of spectroscopy (IRIS, HINODE) are mainly based on the information about minor ions. Minor ions do not have an influence on macroscopic dynamics, so they can be included into a description sufficiently simpler, as 'impurities'. It is important to take into account their heating, as it was shown, that they are heated significantly stronger, than e/m comparatively to protons (Kohl et al. 2005), and this is not explained by any model.

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[1] University of Orleans, LPCEE, Orleans, France, anna.tkachenko@cnrs-orleans.fr
[2] Northumbria University, Newcastle upon Tyne, UK

2.2 Basic equations

We consider 3-fluid system, immersed into electric and magnetic fields and take into account the effects of collisional ionization and photorecombination.

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \left(n_e \overrightarrow{V_e} \right) = (K_{ion} - K_{rec}) n_n n_e, \tag{2.1}$$

$$\frac{\partial n_i}{\partial t} + \nabla \cdot \left(n_i \overrightarrow{V_i} \right) = (K_{ion} - K_{rec}) n_n n_i, \tag{2.2}$$

$$\frac{\partial n_n}{\partial t} + \nabla \cdot \left(n_n \overrightarrow{V_n} \right) = (-K_{ion} + K_{rec}) n_n n_e, \tag{2.3}$$

$$\begin{aligned} m_e n_e \left(\frac{\partial \overrightarrow{V_e}}{\partial t} + (\overrightarrow{V_e} \cdot \nabla) \overrightarrow{V_e} \right) &= -\nabla n_e T_e - e n_i \left(\overrightarrow{E} + \frac{1}{c} \left[\overrightarrow{V_e} \times \overrightarrow{B} \right] \right) \\ &\quad -\beta_0 n_e \nabla T_e - \alpha_{ne} (\overrightarrow{V_e} - \overrightarrow{V_n}) - \alpha_{ie} (\overrightarrow{V_e} - \overrightarrow{V_i}) \end{aligned} \tag{2.4}$$

$$\begin{aligned} m_i n_i \left(\frac{\partial \overrightarrow{V_i}}{\partial t} + (\overrightarrow{V_i} \cdot \nabla) \overrightarrow{V_i} \right) &= -\nabla n_i T_i - m_i n_i g_\circ + e n_i \left(\overrightarrow{E} + \frac{1}{c} \left[\overrightarrow{V_i} \times \overrightarrow{B} \right] \right) \\ -\alpha_{ni} (\overrightarrow{V_i} - \overrightarrow{V_n}) - \alpha_{ie} (\overrightarrow{V_i} - \overrightarrow{V_e}) &- m_i n_i n_n (K_{ion} - K_{rec}) (\overrightarrow{V_i} - \overrightarrow{V_n}), \end{aligned} \tag{2.5}$$

$$\begin{aligned} m_n n_n \left(\frac{\partial \overrightarrow{V_n}}{\partial t} + (\overrightarrow{V_n} \cdot \nabla) \overrightarrow{V_n} \right) &= -\nabla n_n T_n - m_n n_n g_\circ \\ -\alpha_{ni} (\overrightarrow{V_n} - \overrightarrow{V_i}) - \alpha_{ne} (\overrightarrow{V_n} - \overrightarrow{V_e}) &- m_n n_i n_n (K_{ion} - K_{rec}) (\overrightarrow{V_n} - \overrightarrow{V_i}), \end{aligned} \tag{2.6}$$

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{m_e n_e}{2} V_e^2 + n_e I + \frac{3}{2} n_e T_e \right) + \nabla \cdot \left(\left[\frac{m_e n_e}{2} V_e^2 + n_e I + \frac{5}{2} n_e T_e \right] \overrightarrow{V}_e + \overrightarrow{q} \right) &= \\ n_e e \overrightarrow{E} \overrightarrow{V}_e + Q + \overrightarrow{V}_e (-\alpha_{ne} (\overrightarrow{V}_e - \overrightarrow{V}_n) - \alpha_{ie} (\overrightarrow{V}_e - \overrightarrow{V}_i) - \beta_0 n_e \nabla T_e), \end{aligned} \tag{2.7}$$

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{m_i n_i V_i^2}{2} + \frac{3}{2} P_i \right) + \nabla \cdot \left(\overrightarrow{V}_i \left[\frac{m_i n_i V_i^2}{2} + \frac{5}{2} P_i \right] \right) &= \\ Q - \alpha_{in} \overrightarrow{V}_i (\overrightarrow{V}_i - \overrightarrow{V}_n) - \alpha_{ie} \overrightarrow{V}_i (\overrightarrow{V}_i - \overrightarrow{V}_e) + \frac{m_i n_i V_n^2}{2} K_{ion} n_n - \frac{m_i n_i V_i^2}{2} K_{rec} n_n, \end{aligned} \tag{2.8}$$

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{m_n n_n V_n^2}{2} + \frac{3}{2} P_n \right) + \nabla \left(\overrightarrow{V}_n \left[\frac{m_n n_n V_n^2}{2} + \frac{5}{2} P_n \right] \right) &= \\ Q - \alpha_{in} \overrightarrow{V}_n (\overrightarrow{V}_n - \overrightarrow{V}_i) - \alpha_{ie} \overrightarrow{V}_n (\overrightarrow{V}_n - \overrightarrow{V}_e) - \frac{m_n n_n V_i^2}{2} K_{ion} n_i + \frac{m_n n_n V_i^2}{2} K_{rec} n_i, \end{aligned} \tag{2.9}$$

$$\overrightarrow{J_m} = -D \nabla N_m. \tag{2.10}$$

3 Numerical modelling

The code used for our modelling is a multi-dimensional parallel solver of systems of hyperbolic differential equations on an arbitrary Cartesian grid. It has already been configured to solve the systems of hydrodynamic, magneto-hydrodynamic and two-fluid magneto-hydrodynamic (ions + neutrals) equations. We modified the system of equations to include the continuity and momentum equations for electron plasma component, as described in the previous section. One-dimensional semi-empirical models by (Fontenla et al. 2009), (Fontenla 2005), and (Hudson 2007) are used as plane-parallel initial plasma configuration for tests.

3.1 Figures

At current state of work we make tests, performing simulations with large number of timesteps. To illustrate, we have plotted the result of the 1000 timesteps ($dt = 9.2 \mu s$) simulation (Fig.1.): **Top:** Proton altitude profiles of a) mass density in g/cm^3 and b) pressure in $dyne/cm^2$. **Bottom:** Neutral hydrogen altitude profiles of c)mass density and d)pressure. The altitude scale is in cm above the photospheric bottom. We obtain a slight change in all parameters, what is only visible on a proton mass density profile.

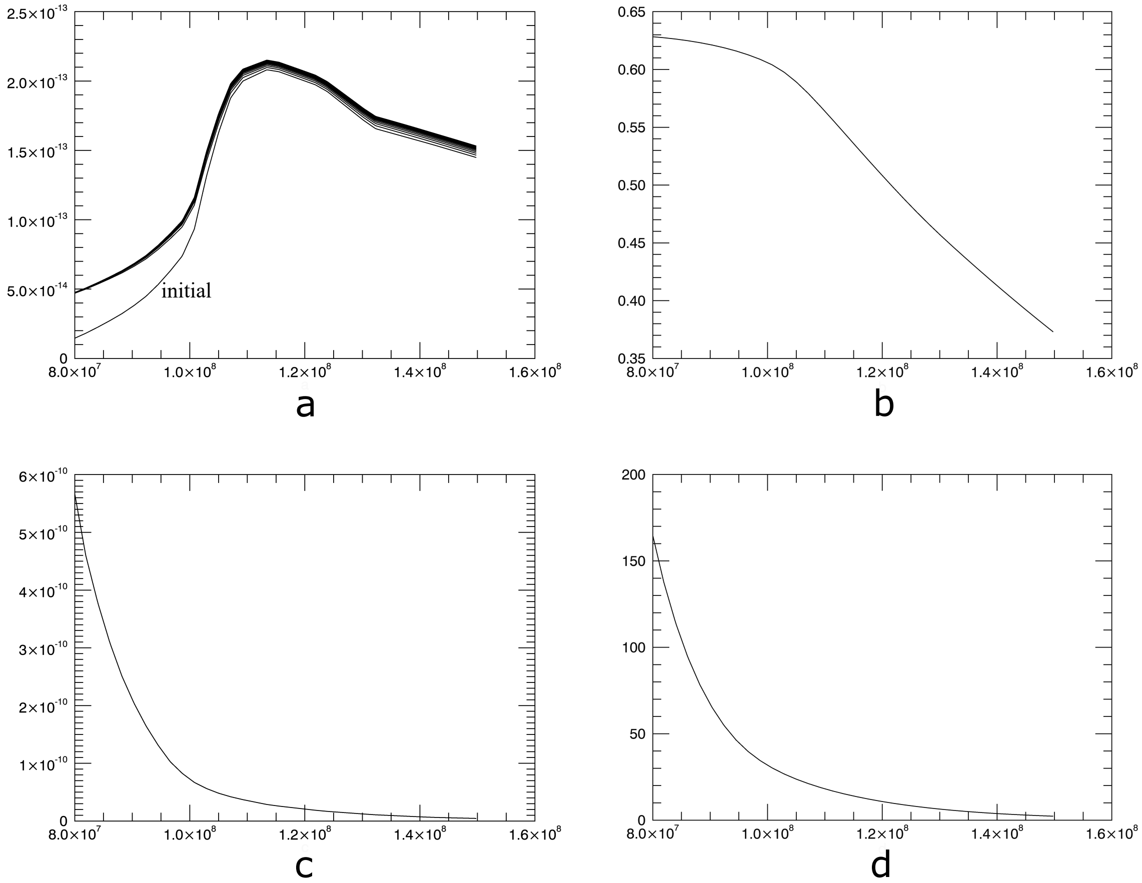

Fig. 1. Simulation profiles of proton and neutral hydrogen parameters in chromosphere.

4 Conclusions

At this moment we are verifying the operation of the hydrodynamic part of the code and performing tests. As the next step we are going to add the electric and magnetic fields and minor ions' diffusion.

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