THE MULTI FLUID DESCRIPTION OF CHROMOSPHERIC MOTIONS

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FORMULATION OF PROBLEM

> The main problems of coronal physics are the coronal heating and the acceleration of the solar wind

> Existing models of this phenomenon 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 phenomena, taking place in coronal region

> VAL-C models for Quiet Sun demonstrate, that collision rates remain high in chromospheric region (Fig.1a). Moreover, Fig.1b shows, that the ionization rate of gas remains very low, up to the beginning of TR

> Reconnection models are not applicable to this region

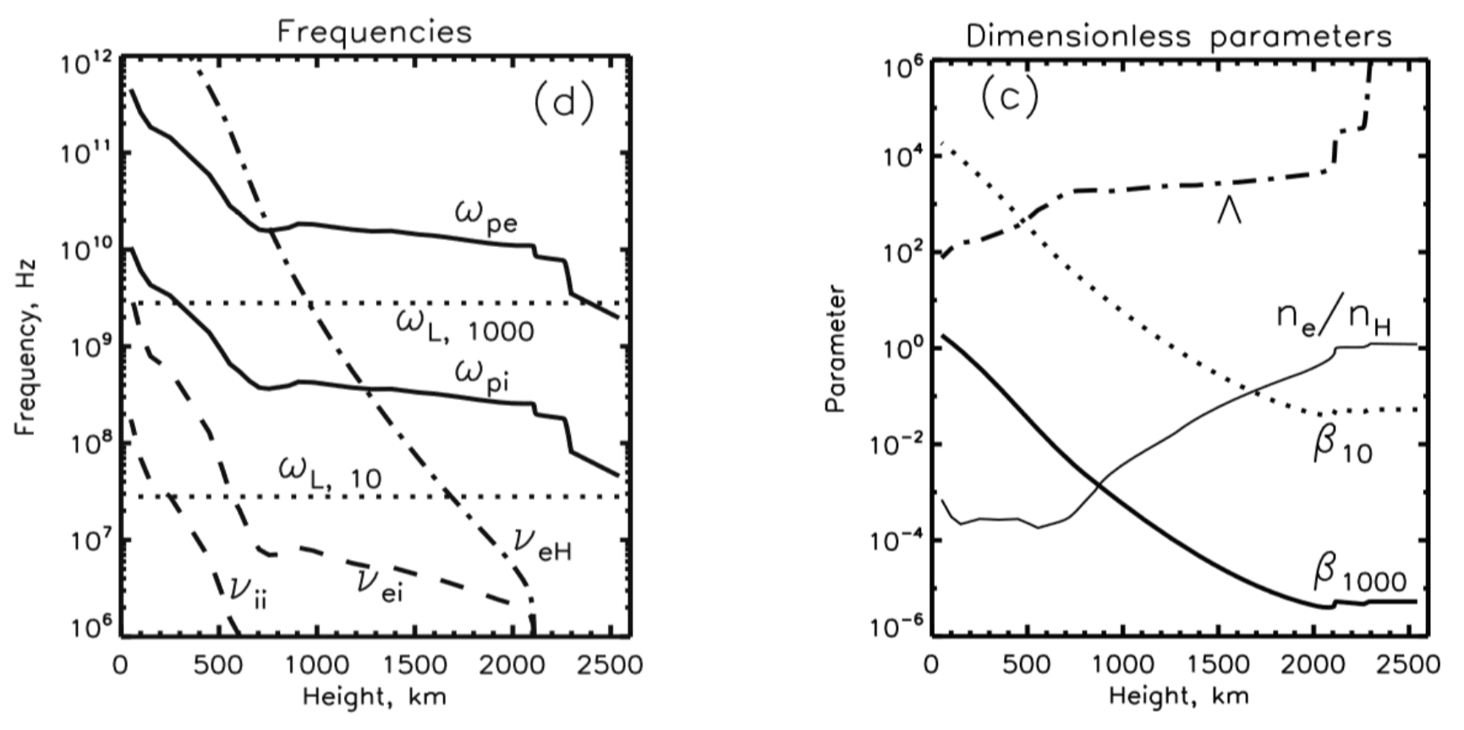

Fig.1. Various plasma parameters in VAL-C model (courtesy of H.Hudson [1]).

>The ideal MHD models consider fully ionized media, do not take into account important phenomena, taking place in the chromosphere

>For illustration, we present an analysis of the data of simulation of Abbett et al., (see Fig.2) near temperature minimum region [2]. One can see, that $\vec{v} \times \vec{B}$ results the enormously high electric field

>With finite conductivity physical processes are very far from ideal MHD description.

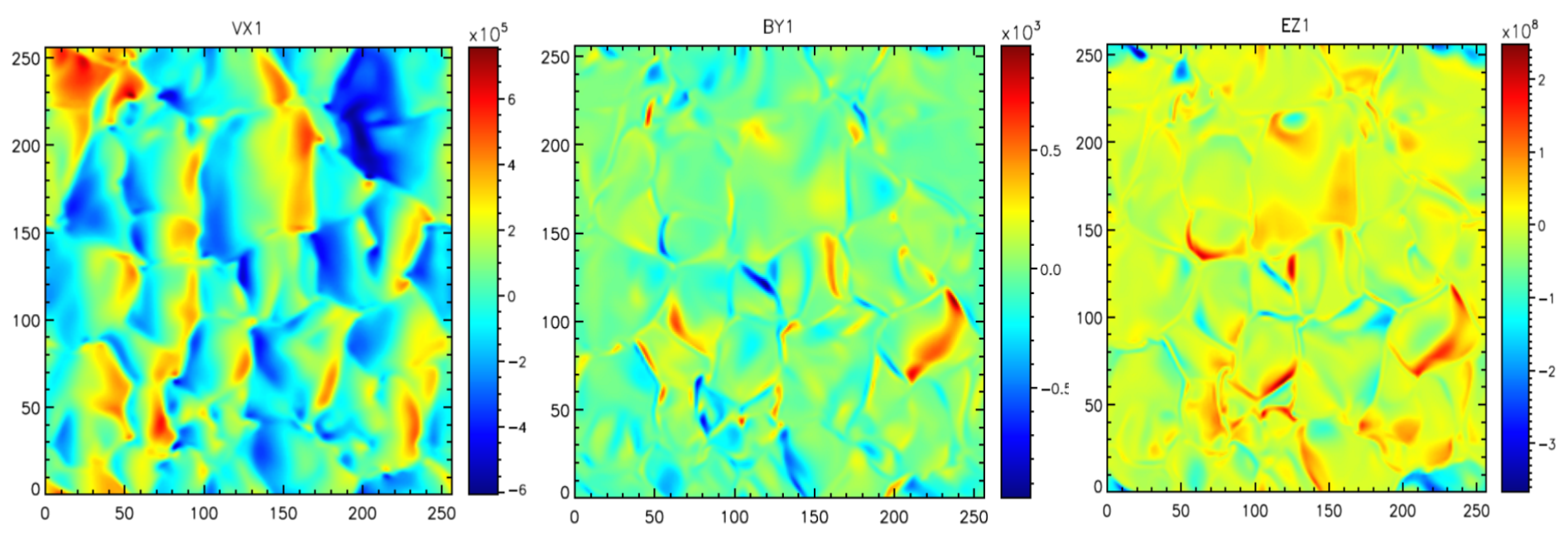

Fig.2. 3D MHD simulations near temperature minimum by Abbett et al. From left to right: velocity, magnetic field, resulting electric field.

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 (Fig.3).

> Minor ions do not have an influence on macroscopic dynamics, so they can be included into a description sufficiently simpler, as 'impurities'

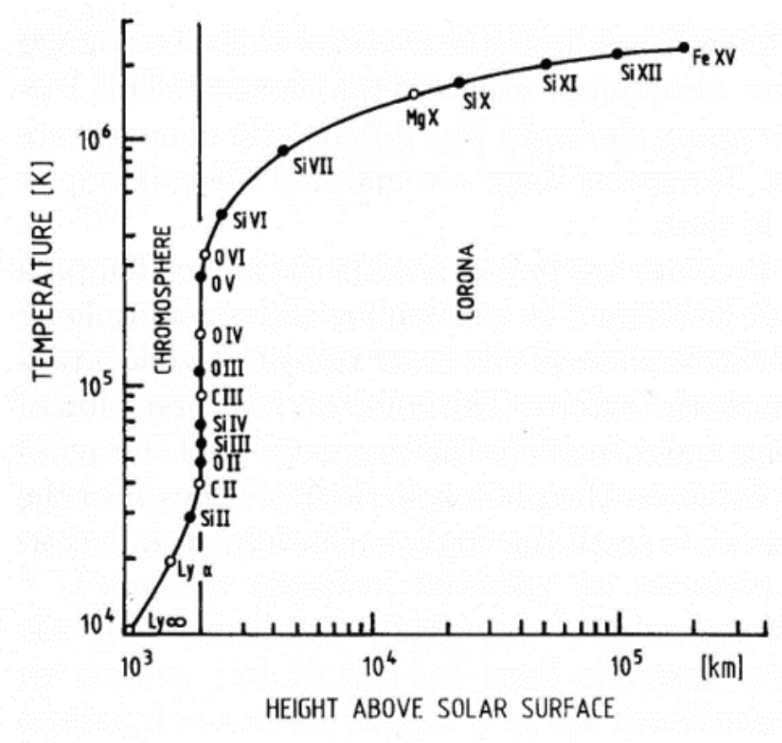

Fig.3. Temperature profile and typical emission lines of TR.

> 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 (see Fig.3.)

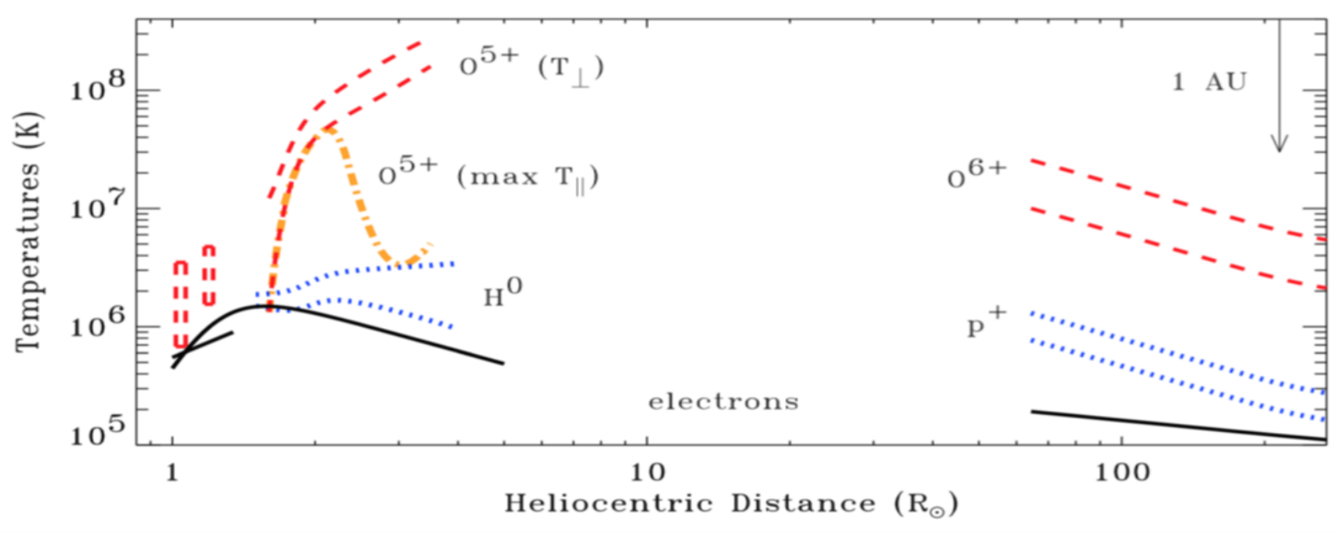

Fig.4. Radial dependence of temperature in polar coronal holes at solar minimum from remote sensing and in-situ measurements [3].

THE MODEL EQUATIONS

> We consider 3-fluid system, immersed into electric and magnetic fields

> We take into account the effects of collisional ionization and recombination.

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \left(n_e \vec{V_e}\right) = (K_{ion} - K_{rec}) n_n n_e, \qquad (1)$$

$$\frac{\partial n_i}{\partial t} + \nabla \cdot \left(n_i \vec{V_i}\right) = (K_{ion} - K_{rec}) n_n n_i, \qquad (2)$$

$$\frac{\partial n_n}{\partial t} + \nabla \cdot \left(n_n \vec{V_n}\right) = (-K_{ion} + K_{rec}) n_n n_e, \qquad (3)$$

$$\begin{aligned} m_e n_e \left(\frac{\partial \vec{V_e}}{\partial t} + (\vec{V_e} \cdot \nabla)\vec{V_e}\right) &= -\nabla n_e T_e \\ - e n_i \left(\vec{E} + \tfrac{1}{c}\left[\vec{V_e} \times \vec{B}\right]\right) &- \beta_0 n_e \nabla T_e \\ - \alpha_{ne}(\vec{V_e} - \vec{V_n}) - \alpha_{ie}(\vec{V_e} - \vec{V_i}), & \qquad (4) \end{aligned}$$

$$\begin{aligned} m_i n_i \left(\frac{\partial \vec{V_i}}{\partial t} + (\vec{V_i} \cdot \nabla)\vec{V_i}\right) &= -\nabla n_i T_i \\ - m_i n_i g_\circ + e n_i \left(\vec{E} + \tfrac{1}{c}\left[\vec{V_i} \times \vec{B}\right]\right) & \\ - \alpha_{ni}(\vec{V_i} - \vec{V_n}) - \alpha_{ie}(\vec{V_i} - \vec{V_e}) & \\ - (K_{ion} - K_{rec}) m_i n_i n_n (\vec{V_i} - \vec{V_n}), & \qquad (5) \end{aligned}$$

$$\begin{aligned} m_n n_n \left(\frac{\partial \vec{V_n}}{\partial t} + (\vec{V_n} \cdot \nabla)\vec{V_n}\right) &= -\nabla n_n T_n \\ - m_n n_n g_\circ - \alpha_{ni}(\vec{V_n} - \vec{V_i}) - \alpha_{ne}(\vec{V_n} - \vec{V_e}) & \\ - (K_{ion} - K_{rec}) m_n n_i n_n (\vec{V_n} - \vec{V_i}), & \qquad (6) \end{aligned}$$

$$\begin{aligned} &\frac{\partial}{\partial t}\left(\tfrac{m_e n_e}{2} V_e^2 + n_e I + \tfrac{3}{2} n_e T_e\right) \\ &+ \nabla \cdot \left(\left[\tfrac{m_e n_e}{2} V_e^2 + n_e I + \tfrac{5}{2} n_e T_e\right] \vec{V}_e + \vec{q}\right) \\ &= n_e e \vec{E} \vec{V}_e + Q + \vec{V}_e(-\alpha_{ne}(\vec{V}_e - \vec{V}_n) \\ &- \alpha_{ie}(\vec{V}_e - \vec{V}_i) - \beta_0 n_e \nabla T_e), \qquad (7) \end{aligned}$$

$$\begin{aligned} &\frac{\partial}{\partial t}\left(\frac{m_i n_i V_i^2}{2} + \tfrac{3}{2} P_i\right) + \nabla \cdot \left(\vec{V}_i \left[\frac{m_i n_i V_i^2}{2} + \tfrac{5}{2} P_i\right]\right) \\ &= Q - \alpha_{in} \vec{V}_i (\vec{V}_i - \vec{V}_n) - \alpha_{ie} \vec{V}_i (\vec{V}_i - \vec{V}_e) \\ &+ \frac{m_i n_i V_n^2}{2} K_{ion} n_n - \frac{m_i n_i V_i^2}{2} K_{rec} n_n, \qquad (8) \end{aligned}$$

$$\begin{aligned} &\frac{\partial}{\partial t}\left(\frac{m_n n_n V_n^2}{2} + \tfrac{3}{2} P_n\right) + \nabla \left(\vec{V}_n \left[\frac{m_n n_n V_n^2}{2} + \tfrac{5}{2} P_n\right]\right) \\ &= Q - \alpha_{in} \vec{V}_n (\vec{V}_n - \vec{V}_i) - \alpha_{ie} \vec{V}_n (\vec{V}_n - \vec{V}_e) \\ &- \frac{m_n n_n V_i^2}{2} K_{ion} n_i + \frac{m_n n_n V_i^2}{2} K_{rec} n_i, \qquad (9) \end{aligned}$$

> For minor ions we apply simplified consideration:

$$\vec{J_m} = -b_m \vec{E} N_m, \qquad (10)$$

> here b_m - mobility, is calculated as for the motion of heavy ions in a light gas

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.

> At current state of work we make tests, performing 1000 time steps with dt=0.00000092s, and obtain rather small change in proton abundance and we validate the operation of the code

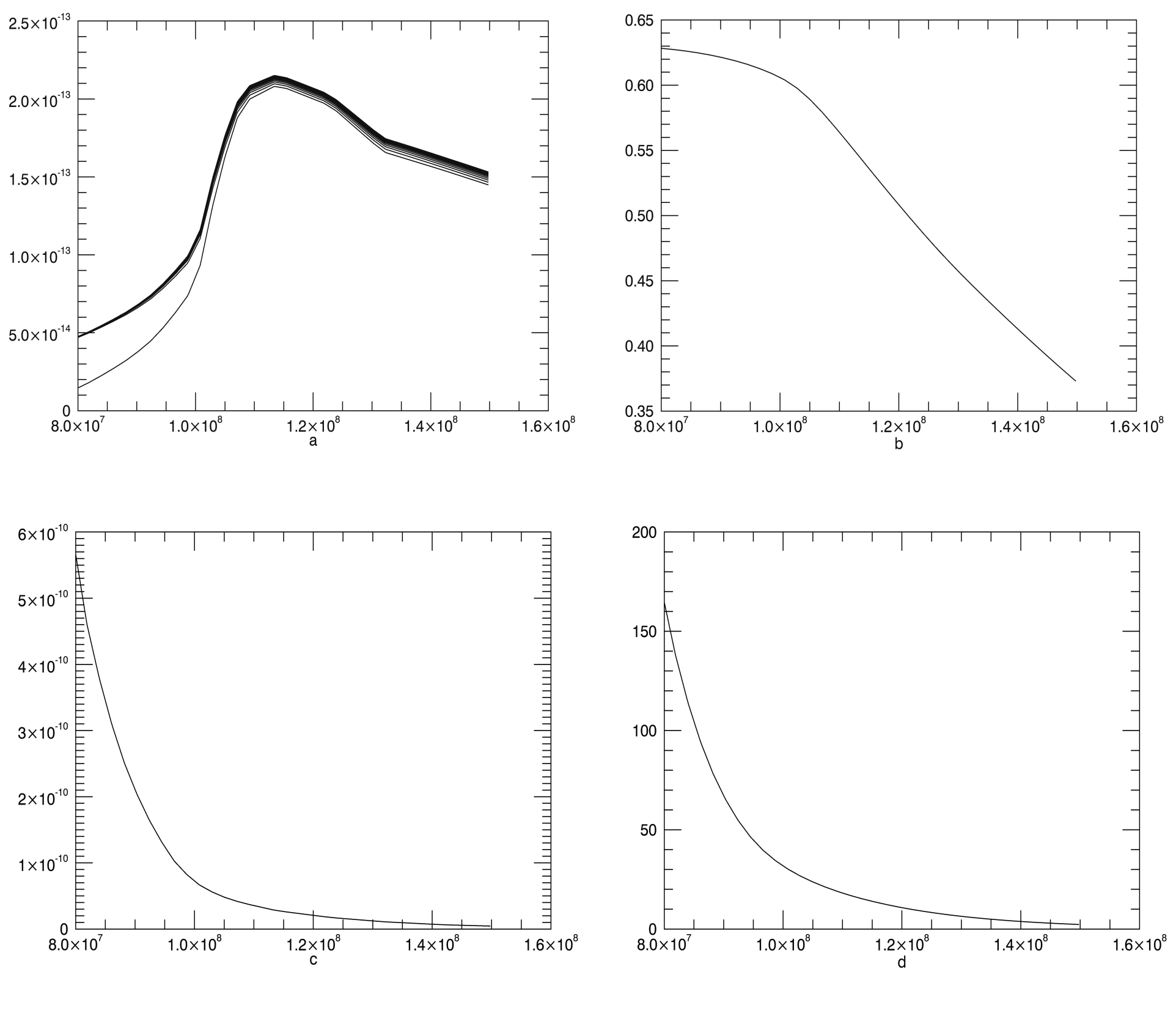

Fig.5. The chromospheric initial model, used for simulations: altitude profiles of : a) proton mass density, b) proton pressure, c) neutral hydrogen mass density, d) neutral hydrogen pressure. Mass densities in g/cm^3, pressure in dyne/cm^2.

INSTEAD OF CONCLUSION

> At this point, we are testing the code to be capable to solve the system of equations (1)-(9)

> As the next step, we plan to model TR and the region of high ionization to study the role of the electric field for processes of coronal heating and solar wind acceleration .

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