Simulations of the Dynamics of Small Scale Magnetic Fields in the Lower Solar Atmosphere with regard to the Atmospheric Heating Problem

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Abstract: Due to the limited observation capacities concerning the chromosphere the question about the cause and mechanism of coronal heating is yet an unsolved one. Hence we require sophisticated simulation models of the regarding layers of the solar atmosphere in order to obtain revealing results concerning the processes within the chromosphere. Therefore, we implemented a new numerical code which performs a two-fluid 2.5D magnetohydrodynamics (MHD) simulation of the dynamics from the upper convection zone up to the transition region. Developed from the Total Variation Diminishing Lax-Friedrichs scheme (TVDLF; Tóth and Odstrčil, 1996), the numerical code includes the effects of ion-neutral collisions, ionisation/recombination, thermal/resistive diffusivity and collisional/resistive heating. As a next step of research the simulation code will be tested and its subsequent results shall then be compared to Hinode SOT/SP data regarding the chromospheric and coronal heating problem.

Introduction:

To the present day there is no satisfying solution to the chromospheric and coronal heating problem, i.e. it is not well understood yet why the upper layers of the Sun possess higher temperatures than the surface of the Sun (see Fig.1). To keep up these high temperatures there must be some sort of heating mechanism. In the literature, we encounter two different basic concepts which are capable of explaining this behaviour, namely wave heating and heating by reconnection. One possible source for these heating processes is the dynamics of small scale magnetic fields in the photosphere. These dynamic processes can cause different forms of MHD-waves which propagate into the chromosphere and/or lead to reconnection (see Fig. 2).
In order to describe and explain the dynamics of these magnetic fields and their effects in the chromosphere, numerical simulations regarding the required region of the Sun are essential. For that purpose we use a two-fluid model which describes the layers from the upper convection zone of the photosphere up to the transition region.
We developed a numerical two-fluid MHD code which performs a 2.5D simulation of the above described dynamic processes and which includes the effects of ion-neutral collisions, ionisation/recombination, thermal/resistive diffusivity and collisional/resistive heating. Finally our code will be tested and the results shall be compared to Hinode SOT/SP data to get useful information concerning the chromospheric and coronal heating problem.

Simulation Model:

For our numerical simulation we use the two-fluid model of Smith and Sakai (2008). The equations in this model describe two-fluid (ion-neutral) plasmas. The general formulation of the set of these MHD equations in two dimensions can be written as

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}(\mathbf{U})}{\partial x} + \frac{\partial \mathbf{G}(\mathbf{U})}{\partial y} = \mathbf{S}(\mathbf{U})$$

Here U denotes the vector of the conserved variables, which are built up of the primitive variables plasma density, pressure, velocity and magnetic field given by ρ_i, p_i, $\mathbf{v}_i$, $\mathbf{B}$ for i=n,p.The subscripts n and p refer to the neutral and the ion (proton) fluid. F(U) and G(U) represent the fluxes in x- and y-direction whereas S(U) denotes the source term. Hence we are dealing with an initial value (time evolution) hyperbolic flux-conservative system of partial differential equations in two space dimensions.
The source term S(U) describes the effects of ionisation/recombination, ion-neutral drag and collisional heating. Moreover, the source term includes neutral and ion heat flux, which incorporates thermal conduction and Joule heating and also the magnetic diffusivity. The adiabatic constant is given by $\gamma=5/3$.

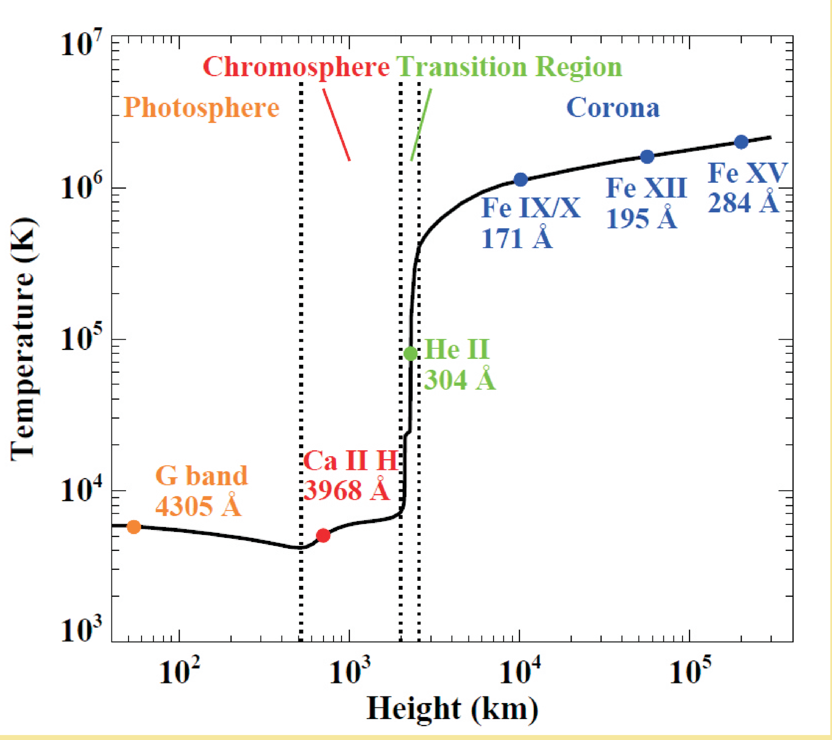

Fig.1:Temperature profile in the solar atmosphere as a function of height.Taken from Yang et al. 2013.

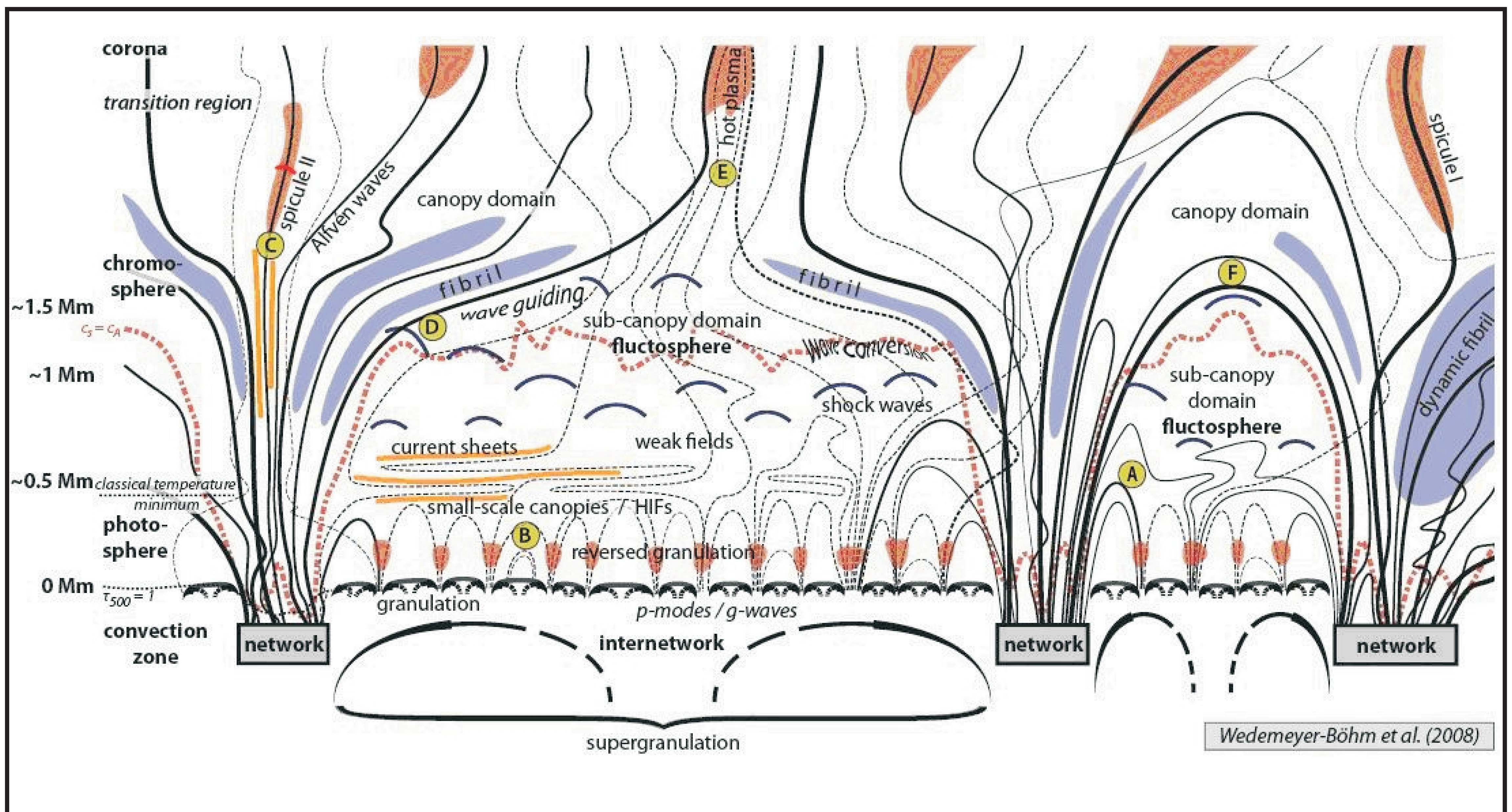

Fig.2: Schematic, simplified structure of the lower quiet Sun atmosphere. Taken from Wedemeyer-Böhm et al. 2009.

Numerical Scheme:

Our newly developed two-fluid 2.5D numerical code applies the TVDLF-scheme. This method makes use of the constraint that the total variation of the analytical solution of a linear system of hyperbolic equations does not increase in time. It is the simplest version of a TVD scheme and it is built on the first order Lax-Friedrichs scheme. The advantages of using the TVDLF method are:

i) the algorithm is quite easy to implement
ii) no spurious numerical oscillations are generated
iii) no Riemann solvers are needed.

• Our algorithm includes the so called **Hancock-scheme**, which is a predictor scheme. The TVDLF method achieves second order accuracy by using this scheme. It is based on the following idea: Within our simulation grid, first cell averages are used for predicting the values of the conserved quantities at cell edges at an auxiliary time step. Afterwards, these predicted values are used to update the solution.

• To avoid spurious oscillations so called slope limiters can be used. In the first version of our code we used the **Woodward-limiter**.

• In order to reduce numerical diffusion we use a diffusive flux Φ^{TVDLF}, which includes the local Courant number.

• Moreover, to accomodate the two spatial dimensions in our simulation, we use an **alternating-direction implicit method (ADI)**, which is a noniterative procedure for solving multidimensional partial differential equations.

• Furthermore, in the first version of our simulation-code, we use a **field-interpolated central differencing scheme** (cf. Tóth, 2000) to maintain the div B = 0 constraint numerically, which has to be fulfilled in every single time step.

• In order to include the source term in our algorithm we use the **four stage Runge-Kutta method**, which is put before and after applying the two different dimensional splitting operators.

Outlook:

The next step of research will be to test our simulation code and to compare the results to Hinode SOT/SP data regarding the atmospheric heating problem.
Moreover, for facilitating parallelization of the algorithm, we intend to use other techniques for the divergence cleaning, like the field-interpolated constrained transport scheme or projection schemes (cf. Tóth, 2000).
Additionally we will use different slope-limiters, like e.g. minmod or superbee limiter, within the Hancock-scheme.
Beside the use of periodic boundary conditions we also want to implement transmissive boundary conditions and compare the different results.
Furthermore, we will use different methods for solving the ordinary differential equations in every time step and compare the outcome to the simulation results regarding accuracy and computing time.
Finally we intend to fully parallelize the existing code and extend it to three spatial dimensions.

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