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3D radiative transfer with continuum and line scattering in low arbitrary velocity fields

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Abstract. With the increasing computer power of modern supercomputers, full 3D radiative transfer calculations with scattering is becoming more and more feasible. The PHOENIX/3D code is a first step towards realistic 3D model atmospheres with scattering in the line and the continuum. Numerous 3D hydro-dynamical codes exist, for example the FLASH or the CO^5BOLD, which can calculate 3D hydro-dynamical structures for, e.g., the Sun. This work concentrates on bringing the two approaches together in the sense of doing realistic, time-independent, radiative transfer with line scattering under considerations of the intrisitc velocity fields in a snapshot of the 3D hydro structure.

Key words. 3D radiative transfer - scattering, 3D radiative transfer - velocity field

1. Introduction

The PHOENIX/3D code, which is used as the basis of this work, is set up in different 3D coordinate systems (Spherical, Cartesian, Cylindrical and Cartesian with Periodic Boundary Conditions (PBCs)) and can handle continuum and line scattering. It can also treat homologous flows ($v \sim r$) in spherical geometry in the comoving frame (CMF), which is required to simulate the atmospheres of, e.g., supernovae (Baron, Hauschildt & Chen 2009).

The implementation of a 3D CMF method for arbitrary velocity fields is possible but still needs a huge amount of memory and is computationally very expensive, see Knop, Hauschildt & Baron (2009). Whereas the approach in the Eulerian (Observer's) frame requires only a small amount of additional memory compared to the regular PHOENIX/3D requirements. This is very important in large atmosphere grids (even on supercomputers) where the storage requirements stretch the limits of the machines.

3D hydro-dynamic simulations are usually performed in a 3D cubic grid with PBCs, where the atmosphere is thought to be consisting of numerous atmospheric elements. For this reason the cubic PBC part of the PHOENIX/3D code (Hauschildt & Baron 2008) was modified. In Seelmann et al. (2009) we will extend this work to the other geometrical setups of the PHOENIX/3D code.

2. Approach

The simple two-level model atom approach (assuming full redistribution) was used. In this setup, the velocity field changes the profile of the atom's absorption, depending on the orien-

Send offprint requests to: A.M. Seelmann tation of the flow and the cosine of the characteristic in the volume element (Voxel). This causes a change in the opacity seen by the atom and leads to a shift to smaller or greater wavelengths in the spectrum. The Λ^* Operator, which is necessary to treat the scattering in a realistic manner, was modified to be consistent with the new formal solution caused by the velocity field.

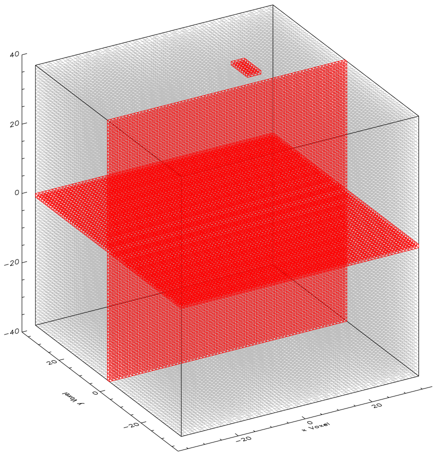

Fig. 1. The 3D atmosphere grid. The red (dark grey) marked planes show the positions in the grid of the plots in Figure 2, 3 and 4.

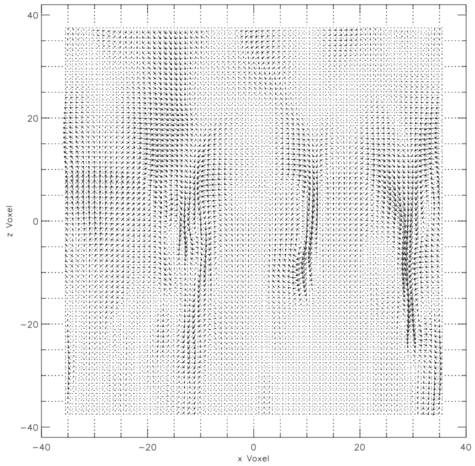

Fig. 2. The velocity field in the central x-z plane.

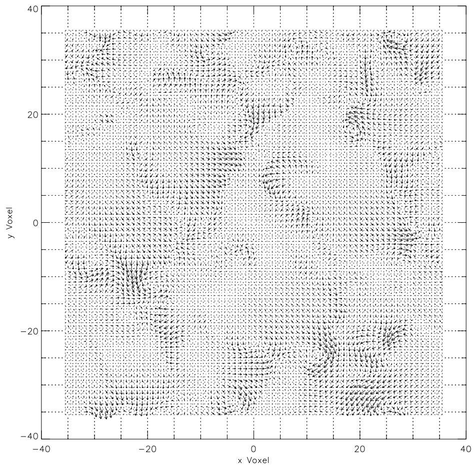

Fig. 3. The velocity field in the central x-y plane.

3. Results

A computed 3D hydro structure snapshot of a radiation hydro-dynamical simulation of convection in the solar atmosphere from Ludwig (Caffau, et al. 2007) was used for the test calculations. In this structure the maximum velocity is $|v_{max}| \sim 10kms^{-1}$, the mean velocity is about $|v_{mean}| \sim 2.5kms^{-1}$. The radiation transport calculations were performed on a 35 x 35 x 37 voxel grid with 128^2 angle points for testing purposes and to save computer resources. It can easily be extended to higher resolutions and more angle points if enough computer power and memory is available.

Figure 1 shows the 3D voxel grid, the boundary conditions were applied on the x-z and y-z faces. A characteristic which leaves those faces is continued on the opposite side. The red (dark grey) marked planes in the box show the positions in the 3D grid of the velocity field plots shown in Figure 2 and 3. The red (dark grey) marked area on the top of the 3D grid outlines the voxels in which the spectra from Figure 4 arises. The computed atmospheres presented here do not

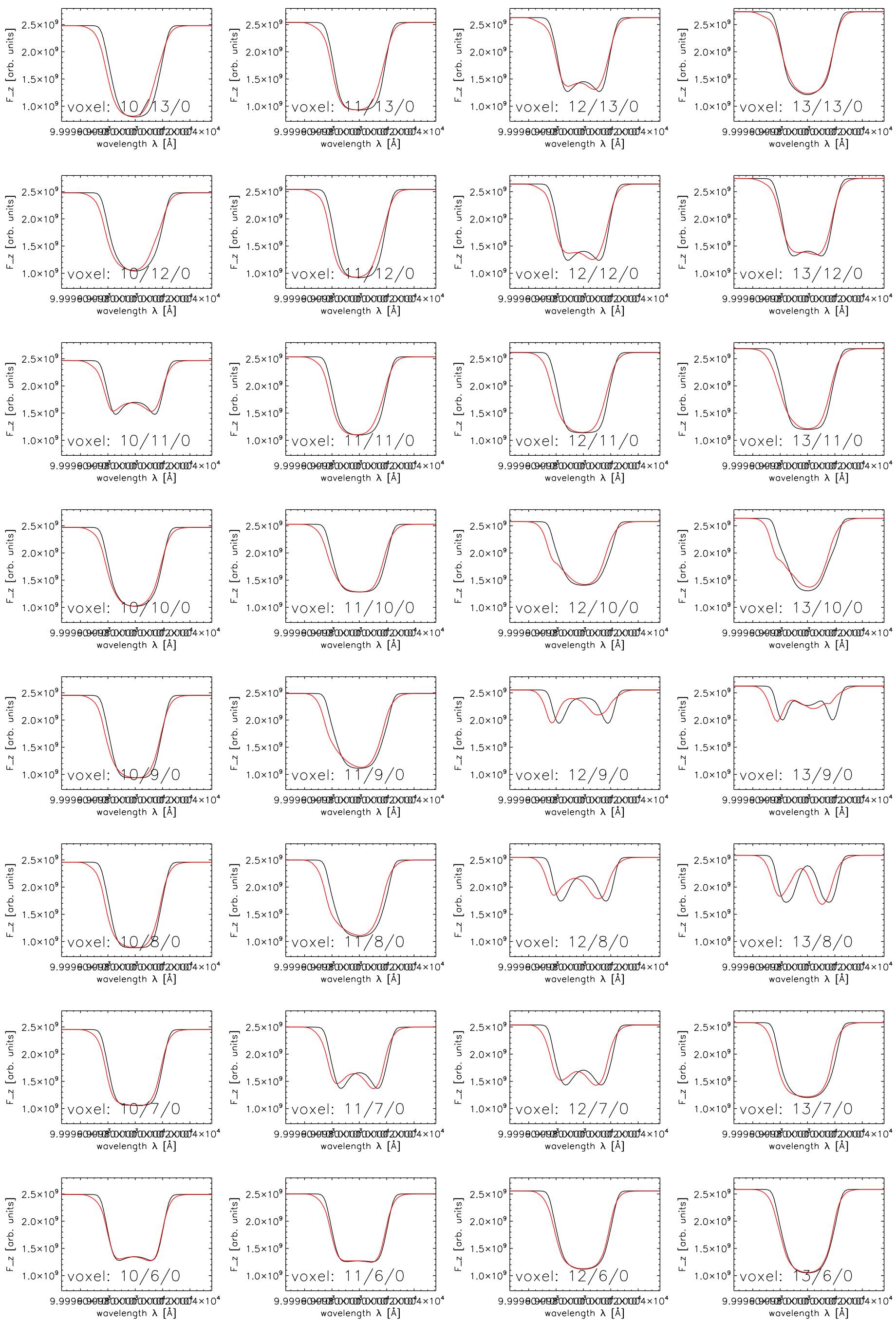

Fig. 4. The voxel spectra from the outlined Voxel in Figure 1 on top on the grid. Black: Spectra without consideration of the velocity field, red (dark grey): Spectra with consideration of the velocity field.

include line / continuum scattering due to a lack of time, see Seelmann et al. (2009).

4. Conclusion

To do realistic 3D hydro-dynamical simulations it is necessary to include the framework presented here in the calculation of the 3D hydro-dynamical structure.

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