MULTI3D: a domain-decomposed 3D radiative transfer code

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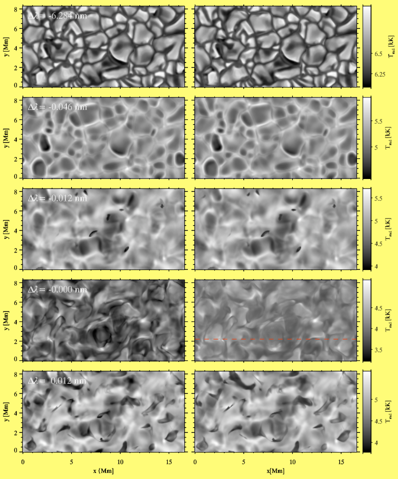

Fig 1: Ca II H intensity

Emergent vertical intensity of the Ca II H line at 396.8 nm. Left-hand column: using a 1D column-by-column solver. Right-hand-column: using the 3D short-characteristic solver. Different rows are at different shifts from the line center, indicated at the top left of each row. Each row has its own brightness scale indicated at the right. 3D effects become important only close to the line core, mainly causing a decrease in RMS intensity variations. The structures remain the same.

Abstract

We present MULTI3D, a 3D radiative transfer code currently under development. It is optimized for computing NLTE problems based on (radiation-)MHD models of stellar atmospheres. MULTI3D is based on MULTI and includes most of the physical mechanisms present in that code. MULTI3D was first written as a serial code by Botnen (1997), and has recently been upgraded to an MPI-parallelized, domain-decomposed version. The code has so far successfully been run on up to 64 processors, solving the NLTE radiative transfer for a six-level Ca II atom with 400 frequency points in an atmosphere of 256 x 128 x 108 grid points.

Short characteristics

The code employs a 3D short characteristics solver for the radiation. It uses second-order Bezier interpolation for the source function, ensuring a positive source function along the characteristics. The radiation is not propagated throughout the whole computational domain per lambda-iteration. Instead, it is propagated over a small (typically 2) number of subdomains per iteration. This means the average radiation field at a given point lags behind several iterations, but will converge to the correct solution when the corrections to the populations become small. This solver ensures a speedup of the code linear with the number of processors *N*. In contrast, he speedup a solver that propagates the radiation throughout the computational domain scales as $N^{2/3}$.

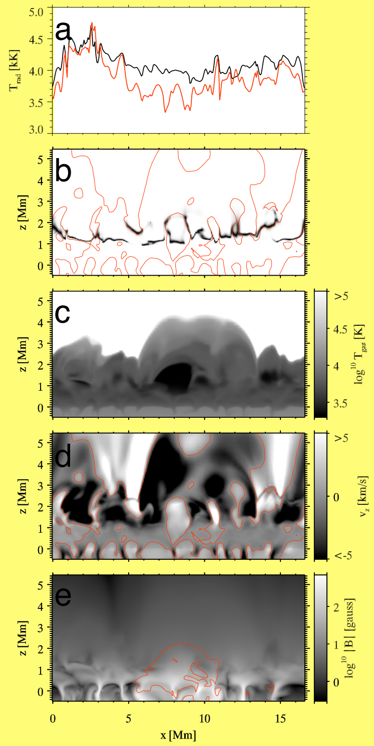

Fig 2: The Ca II H core

a) emergent line core intensity using the 3D solver (black) and the 1D solver (red); b) contribution function, each column scaled to maximum contrast, zero vertical velocity contour is overplotted in red; c) gas temperature; d) vertical velocity, zero contour plotted in red; e) magnetic field strength, the location of the rising fluxrope is indicated with the red contours.

The code

The code employs the complete linearization method of Scharmer & Carlsson (1985), to solve non-LTE problems in 3D geometry. Scattering in lines is treated in complete redistribution while background scattering is coherent. Overlapping transitions are not allowed. Collisional-radiative switching and convergence acceleration are implemented.

Memory usage

3D NLTE radiative transfer codes are very memory intensive. MULTI3D needs to store the average radiation field for each frequency and the intensity at the subdomain boundaries for each frequency and angle between iterations. This amounts to 1GB of memory per subdomain for a subdomain size of 32x32x32, 600 frequency and 24 angle points. This is small enough to fit into memory on today's supercomputers. If the problem demands more memory the persistent data can be written to file in between iterations. This provides the possibility of solving the radiative transfer problem for atoms with a large number of transitions at the penalty of decreased performance.

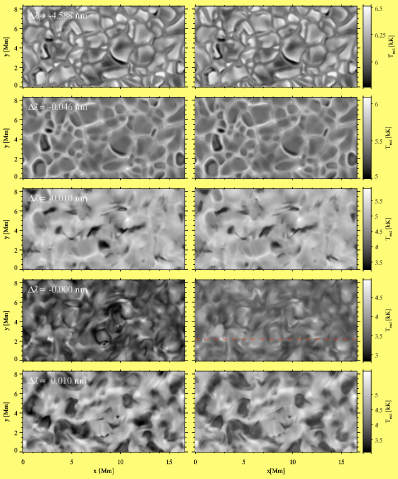

Fig 3: Ca II 8542 intensity

Emergent vertical intensity of the Ca II IR line at 854.2 nm. Left-hand column: using a 1D column-by-column solver. Right-hand-column: using the 3D short-characteristic solver. Different rows are at different shifts from the line center, indicated at the top left of each row.. Each row has it's own brightness scale indicated at the right. 3D effects become important only close to the line core, mainly causing a decrease in RMS intensity variations. The structures remain the same.

Test computation

We performed a test computation on a snapshot of the radiative-MHD simulation of flux emergence by Martinez-Sykora et al. (2008). The computational domain had 256x128x108 grid points. We used a 5-level-plus-continuum Ca II atom with 400 frequency points and treated the ray quadrature with 24 angles. the computation ran on 64 processors and took one day. Results are shown in the figures. Figs. 1 and 3 compare the vertical emergent intensity of the Ca II H and 854.2 nm IR lines to computations where each column of the atmosphere is treated as plan-parallel. 3D effects become important only very close to the line core and tend to decrease the RMS contrast, but the overall structure remains similar. The dark features visible close to, but not in, the line core are formed higher than the brighter background and caused by strong vertical motion in the upper chromosphere shifting the line core out of the rest-wavelength. Fig. 2 shows the detailed formation of the Ca II H line core intensity along the cut indicated in Figs. 1 and 3. Notice that the emerging flux rope indicated in panel e does not show up in the intensity in panel a. The contribution function in panel b shows a large variation in formation height, from 1 to 2.5 Mm.

References

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Martinez-Sykora, J., Hansteen, V., Carlsson, M., 2008, ApJ, 679, 871
Scharmer, G.B., Carlsson, M., 1985, JCoPh, 59, 56