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THE USE OF ITERATION FACTORS METHOD IN THE SOLUTION OF MULTILEVEL RADIATIVE TRANSFER PROBLEMS IN STELLAR ATMOSPHERES

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Abstract. The NLTE problem of formation of spectral lines is one of the most difficult ones to deal with; due to the important role of scattering processes it is nonlocal and for the multilevel case it is additionally nonlinear. Therefore, the problem requires simultaneous solution of radiative transfer (RT) and statistical equilibrium (SE) equations which can be achieved through iterative procedure. There is still a great need of efficient numerical methods for a solution of NLTE radiative transfer problems as they are a necessary step of stellar atmospheres modelling and other important astrophysical problems. In the thesis we develop fast and accurate numerical method that uses iteration factors.

The method is based on the use of quasi-invariant functions - iteration factors, in a simple iterative procedure. Defined as ratios of the moments (integrals of angles and frequencies) of radiation field intensities, the factors are calculated on the beginning of each iterative step from the current solution and then used to obtain its correction. In the thesis we extend iteration factors method developed for a solution of linear problems - monochromatic problem and two-level atom line transfer problems to the solution of a more generalized multilevel problem of spectral line formation with complete redistribution and no background continuum. The additional difficulty arises from the non linear coupling of atomic level populations and the radiation filed intensities in the corresponding spectral lines. In the thesis we suggest and describe in details four iterative procedures that use two families of iteration factors defined for a constant property medium and two different approaches for a simultaneous solution of nonlinear RT and SE equations: (1) linearization of the equations with respect to all relevant variables and (2) modification of the SE equations in order to make them linear. In both approaches the substitution of the linearized SE equations in the moments of RT equation results in a tridiagonal system that is solved, together with the boundary conditions, by a standard Gaussian elimination procedure. In order to test the convergence properties and accuracy of the suggested procedures we solved a standard benchmark problem of spectral line formation by three-level hydrogen atom in plan-parallel isothermal atmosphere with no background continuum and compared its solutions with those obtained by other methods that solved the same test problem. Additionally we solved the problem of spectral line formation by CaII ions with five levels. We also compared the speed of convergence and the total computational time of our method with those of some other methods in use.

Finally, we formulated and analyzed a more general line transfer problem in variably property atmosphere with background continuum. For its solution we defined four additional families of iteration factors and tested the convergence properties of the procedures that use them on a solution of linear radiative transfer problem for constant and for variable (with optical depth) absorption profile, as well as on multilevel case.

In the conclusion we emphasized that the use of the iteration factors defined in the thesis results in extremely fast convergence to the exact solutions of the problem, with no need of extra mathematical acceleration, necessary for other methods. Also, the use of iteration factors defined for the spectral line as a whole drastically reduces the memory cost and the computational time. The accuracy of the method increases with the number of the grid points, but the very high convergence speed is not affected by the refinement of the grid resolution. So the total computational work scales linearly with the number of the grid points and is couple of times less than needed by other existing methods.