# THE RADIATIVE ENERGY EXCHANGE TERM IN THE STELLAR ATMOSPHERES: ACCURACY AND STABILITY OF NUMERICAL ALGORITHMS

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Time-dependent 3D radiative-magnetohydrodynamic simulations are the most comprehensive theoretical tool for studying structure and dynamics of the stellar atmospheres. Interactions between the radiation and matter are the key ingredient that must be taken into account in these simulations. Under the assumption of local thermodynamic equilibrium, these interactions are fully described by the radiative energy exchange term $Q$ that appears as a source term in the energy conservation equation. The term is defined as a negative divergence of the radiative flux and it is commonly computed by solving the radiative transfer equation (RTE) along the set of rays. As the 3D simulations are exceptionally computationally expensive, it is of uttermost importance to solve RTE efficiently in parallel computing architectures. However, at the same time, it is critical to have numerically stable and accurate solutions although the requirements for accuracy and stability are often competing. In the field of stellar modeling, the method of choice is the short-characteristics (SC) scheme based on the work of Mihalas, Auer & Mihalas (1978). In this method the source function $S$ in the formal solution of RTE is integrated locally over short ray segments. There are many variants of this method implemented in the modern codes where the type of the source function approximation on a segment is the main distinctive feature.

In this contribution, using uniform notation, I first derive different variants of the SC method and classify them into families of solutions. The two principle families are based on the Lagrange and on Hermite approximation equations. Each of the families is then refined based on the accuracy of the approximating polynomial, the position and length of the stencil, and other details of the numerical algorithm. In the Hermite case, the distinctive criterion is the method for computing the first derivative of $S$. Different solutions are analyzed in terms of their accuracy, stability and efficiency. To separate the uncertainties of the formal solver along the ray from uncertainties due to 2D interpolations required in 3D implementation of SC, all variants of the SC method are coded in 1D geometry and implemented on a set of 1D atmospheres extracted from 3D snapshots of realistic RMHD simulations with the MANCHA code (Khomenko et al, 2017, 2018). Some of the 1D atmospheres are smooth and well-behaving, while others contain large gradients in the temperature and mass density that are typical for shock propagation or multiple local extrema typical for the rays traversing the atmosphere at the large inclination angles. Finally, the optimal solution is coded in 1.5D (3D atmosphere where radiation is solved in 1D, column by column) and in the full 3D geometry, and the uncertainties of the method in this complex scenario are evaluated.