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ON RECENT ADVANCES IN RADIATIVE TRANSFER THEORY

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The theory of radiative transfer (RT) is of double importance for astrophysics. On one hand the radiative transfer influences the structure and dynamical behaviour of astrophysical plasma and, on the other, it represents an important tool in spectroscopic diagnostics of the plasma properties.

Among various physical phenomena RT is one of the most difficult to deal with, due to its highly non-local and non-linear nature. The main difficulty arises from an important role of the scattering process which makes properties of the well-distant regions coupled through the radiation field. The physical coupling of the radiation field and the state of the gas is mathematically performed by the simultaneous solution of the corresponding equations of RT and statistical equilibrium (SE). Generally, due to the interlocking effect among different line transitions within a multilevel atom, the coefficients of each of the two systems (RT and SE) depend on the solution of the other in strongly non-linear way. Moreover, the global coupling of the photons across the spectrum and the effects on the overall structure of the medium are implied by the constraint of energy balance.

Although the basic physics of the problem and relevant equations have been known for a long time, the solution of RT problem was rather slow due to mathematical difficulties. Different RT problems and the corresponding methods arose from different sophistication degree of the physical input and of the assumptions made.

Large-scale computational work has begun in the mid-60s with the calculations of so-called classical (static radiative equilibrium LTE) atmospheric models. Removal of the LTE assumption (NLTE) soon required new algorithms that could handle the non-linear coupling of all relevant variables in a completely self-consistent manner. It was realized by the powerful method of complete linearization - a direct solution of the problem equations. The method developed for stellar atmosphere modelling and its simplification to NLTE spectral synthesis were widely used during 1970s. However, being very time and memory consuming, it was in practice restricted to simplified atomic models and geometries.

A tremendous progress achieved over last years in high quality observations and in computational facilities has stimulated the efforts to improve the physical realism in stellar atmospheric modelling, our understanding and theoretical interpretation of the observed phenomena. Observations have shown that real stellar environment departs significantly from classical homogeneous, steady-state model, that it is often highly dynamic and spatially inhomogeneous, hence opening many interesting RT problems: time-dependent RT, multidimensional RT, RT in inhomogeneous media, transfer of polarized radiation, partial redistribution, line-blanketed NLTE atmospheres, RT in expanding media, modelling of radiatively driven stellar winds and NLTE computation of their spectra, etc.

Many of these problems have been solved during the last decade with high accuracy. The progress in stellar modelling is made primarily thanks to the impressive advances in computational methods. In 1980s the iterative techniques have become again very popular because of much simpler algorithm in respect to the direct ones. A class of methods known as Accelerated Lambda Iteration (ALI) has been widely applied. Now it is possible to tackle certain RT problems that were unapproachable a decade ago. Besides, fits to the observed data are significantly improved by the use of more accurate and more numerous spectroscopic data.

Due to limits of time and the subject extensiveness this review will be restricted to the most important results achieved in the theory of RT over last fifteen years with a special emphasize given to some most recent approaches to the formulation and solution of RT problems. Primarily it concerns new structural approach to the solution of a global (astro)physical problem comprising new, fast and robust iterative techniques (Implicit Integral Method and Iteration Factors (Profiles) Method). A special attention will be paid to a re-formulation of the line formation theory within the kinetic approach, quite promising in the treatment of the line transfer problems in laboratory and astrophysical plasma, still one of the most important open problems in the field of RT.