Polarized line scattering theory with applications in astrophysical radiative transfer: a historical perspective

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Abstract

Ivan Hubeny did a fundamental work in the theory of partial frequency redistribution (PFR) and radiative transfer, for more than two decades in the early part of his career. One of the most elegant works of Ivan with his collaborators in that period is the "theory of generalized redistribution functions (GRFs)" for multi-level atoms (the so called Hubeny, Oxenius, Simonneau: HOS theory). This ground breaking work on GRFs represents the high point of his contribution to this field. Some of these GRFs are already incorporated in the well known line transfer codes used in the realistic modeling of the observed spectra. The impact of the papers by Ivan on the theory of PFR and line formation, is far reaching and deep, apart from his important work on pure radiative transfer theory. He worked very extensively on applications of the radiative transfer equation (RTE) to a variety of astrophysical situations. The examples of these are:- the improvement of the complete linearization method; extension of ETLA method to include PFR; the work on scaling laws with PFR in probabilistic radiative transfer; and the modeling of the solar Lyman-alpha, Lyman-beta, H-alpha system, among many other topics.

In the first part of this review we include in detail, the relevant literature on the derivation of the unpolarized and polarized PFR functions/ matrices until the current year. A brief review of the work on polarized scattering phase matrices would be given. The phase matrices were derived assuming frequency coherent scattering. Since 1970s the formulation and use of polarized redistribution matrices in RTE has become a standard practice. To a good approximation the redistribution matrices may be expressed as a product of phase matrices and redistribution functions. However a realistic treatment of polarized line scattering requires the use of redistribution matrices themselves in the transfer equation. A survey is made of the literature on the derivation of the PFR functions/ matrices derived by classical, semi-classical, and quantum mechanical formulations, apart from the approximate, and heuristic approaches. In the second part of this review, we dwell upon the numerical methods of solving the NLTE polarized/ unpolarized line RTE with PFR. A historical account is given of the escape probability methods, the classical direct methods, the iterative methods, and other methods like scattering expansion method, etc. Contributions of Ivan to some of these methods are highlighted.

In the third part of this review we give an account of the PFR matrices derived for specific physical mechanisms. Of particular interest are the PFR matrices for:- weak field Hanle effect; Hanle-Zeeman regime; J and F state quantum interference; Paschen-Back effect; lower

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level polarization etc. We also present a review of the methods for polarized RTE in planar, spherical and multi-D media in both the static and moving atmospheres. A comparison is made of the traditionally used angle-averaged approximation to PFR, and the angle-dependent PFR.

Finally, the greatest creation of Ivan with Dimitri Mihalas is the publication of the Magnum opus "Theory of Stellar Atmospheres: An introduction to astrophysical non-equilibrium quantitative spectroscopic analysis" in 2014. Every word of the title speaks for itself. No book has ever been written with such a clarity and depth in the theory, covering at the same time a vast landscape of techniques in the theory of stellar atmospheres. Already known as 'SA3', the book represents a fine gift to the Astrophysical community, and remains evergreen in the decades to come.