Non-LTE models for synthetic spectra of type Ia supernovae
III. An accelerated lambda iteration procedure for the mutual interaction of strong spectral lines in SN Ia models with and without energy deposition

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Context. In type Ia supernova (SNIa) envelopes a huge number of lines of different elements overlap within their thermal Doppler widths, and this problem is exacerbated by the circumstance that up to 20% of these lines can have a line optical depth greater than 1. The stagnation of the lambda iteration in such optically thick cases is one of the fundamental physical problems inherent in the iterative solution of the non-LTE problem, and the failure of a lambda iteration to converge is a point of crucial importance whose physical significance must be understood completely.
Aims. We discuss a general problem related to radiative transfer under the physical conditions of supernova ejecta that involves a failure of the usual non-LTE iteration scheme to converge when multiple strong opacities belonging to different physical transitions come together, similar to the well-known situation where convergence is impaired even when only a single process attains large optical depths. The convergence problem is independent of the chosen frequency and depth grid spacing, independent of whether the radiative transfer is solved in the comoving or observerâ€™s frame, and independent of whether a common complete-linearization scheme or a conventional accelerated lambda iteration (ALI) is used. The problem appears when all millions of line transitions required for a realistic description of SNIa envelopes are treated in the frame of a comprehensive non-LTE model. The only way out of this problem is a complete-linearization approach which considers all ions of all elements simultaneously, or an adequate generalization of the established ALI technique which accounts for the mutual interaction of the strong spectral lines of different elements and which thereby unfreezes the â€œstuckâ€• state of the iteration.
Methods. The physics of the atmospheres of SNIa are strongly affected by the high-velocity expansion of the ejecta, dominating the formation of the spectra at all wavelength ranges. Thus, hydrodynamic explosion models and realistic model atmospheres that take into account the strong deviation from local thermodynamic equilibrium are necessary for the synthesis and analysis of the spectra. In this regard one of the biggest challenges we have found in the modeling of the radiative transfer in SNIa is the fact that the radiative energy in the UV has to be transferred only via spectral lines into the optical regime in order to be able to leave the ejecta. However, convergence of the model toward a state where this is possible is impaired when using the standard procedures. We report on improvements in our approach of computing synthetic spectra for SNIa with respect to (i) an improved and sophisticated treatment of many thousands of strong lines that interact intricately with the â€œpseudo-continuumâ€• formed entirely by Doppler-shifted spectral lines, (ii) an improved and expanc atomic database, and (iii) the inclusion of energy deposition within the ejecta arising from the radioactive decay of mostly 56Ni and 56Co.
Results. We show that an ALI procedure we have developed for the mutual interaction of strong spectral lines appearing in the atmospheres of SNe Ia solves the longstanding problem of transferring the radiative energy from the UV into the optical regime. Our new method thus constitutes a foundation for more refined models, such as those including energy deposition. In this regard we further show synthetic spectra obtained with various methods adopted for the released energy and compare them to observations. In detail we discuss applications of the diagnostic technique by example of a standard type Ia supernova, where the comparison of calculated and observed spectra revealed that in the early phases the consideration of the energy deposition within the spectrum-forming regions of the ejecta does not qualitatively alter the shape of the emergent spectra.
Conclusions. The results of our investigation lead to an improved understanding of how the shape of the spectrum changes radically as function of depth in the ejecta, and show how different emergent spectra are formed as a result of the particular physical properties of SNe Ia ejecta and the resulting peculiarities in the radiative transfer. This knowledge provides an important insight into the process of extracting information from observed SNIa spectra, since these spectra are a complex product of numerous unobservable SNIa spectral features which are thus analyzed in parallel to the observable SNIa spectral features.

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