Consistent Radiative Transfer Models including Time Dependent Energy Deposition for Type Ia Supernovae

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Abstract. Many aspects of the explosion mechanism of Type Ia supernovae (SN Ia) still remain unclear – causing uncertainties in the derived cosmological parameters. Realistic models of the generation and transport of radiation in the ejecta are required which link theoretical explosion models to observations. We aim to construct theoretical spectra and light curves from consistent radiative transfer models that allow to study the dependence of observable features on the physical parameters of the explosion.

1. Introduction

To minimize the systematic errors of cosmological quantities deduced from SN Ia it is essential to have a detailed understanding of the physics involved in these explosions. An important tool are realistic models of the radiation transport within the ejected material which represent the crucial link between theoretical explosion models and observations. The physical conditions within the expanding SN Ia ejecta, however, make this extremely difficult and are the reason that models which allow a reliable, quantitative analysis are still missing. High radiation densities acting on an environment of low matter density, as well as the energy input by $\gamma$-rays and positrons within the atmosphere, do not allow for the simplifying assumptions of LTE. Thus a consistent model requires at minimum the solution of the full non-LTE problem (cf. Pauldrach et al. 1996). Here we outline our project to construct a more consistent theoretical description of SN Ia radiative transfer and describe first steps.

2. The Model

In our approach the description of radiative processes in supernova ejecta is split into two problems: First, the time dependent description of the deposition of radiative energy from the $\gamma$ photons from the $^{56}$Ni and $^{56}$Co decay as well as the trapping of photons in highly opaque, expanding material that leads to the characteristic shape of the light curve. Second, the actual formation of the spectrum that needs to consider only the outer parts of the ejecta where radiation is actually able to emerge (figure 1). Here the time scales for interaction of photons with matter become small compared to the expansion time scale so this part can be treated in a time independent model. In both parts we assume spherical symmetry of the object.

Time dependent energy deposition. In our approach the time dependent part treated with a Monte Carlo (MC) light curve code (Cappellaro et al. 1997) that simulates the propagation and deposition of the $\gamma$ photons and positrons
within the ejecta using an approximate, wavelength independent opacity. The resulting energy deposition in the ejecta is distributed to optical photons. The random walk of these photons on their way through the ejecta is followed until they reach low opacity regions from where they can escape. The amount of emerging energy per time interval determines the light curve of the SN and sets the luminosity for the synthetic spectrum at a given epoch.

**NLTE models and spectral synthesis.** The energy deposition rate at a certain epoch is used as an input to the stationary but much more detailed computation of the radiation transport in full NLTE. This model treats the outer part of the ejecta, assuming a “photosphere” as lower boundary. The code used here was originally developed for the analysis of spectra of hot stars with radiation driven winds (Pauldrach et al. [2001]) and is being modified in order to treat the physical conditions in SN Ia. The code provides a consistent solution of the NLTE rate equations for all relevant elements. The radiation transfer is calculated in detail taking into account all significant sources of opacity and emission. Also, a proper treatment of line blocking and blanketing effects is included. The radiation field at the outer edge of the fully converged model represents the synthetic spectrum of the object, and can be directly compared to observations.

3. **Status and first results**

So far we have derived simplified models, assuming all energy deposition occurs below the photosphere, to test the code for physical conditions in SN Ia. Result of this analysis was that even in deep layers the approximation of LTE does not give an appropriate description of the radiation field (Sauer et al. [2003]). This causes the commonly used diffusion approximation as a lower boundary for the radiative transport equations to break down, resulting in unrealistic temperatures and a too large flux in the red part of the spectrum. Adjustments to this boundary condition have been investigated and are currently being tested. The next step will be to incorporate the results computed with the MC code in the NLTE calculations.

**References**

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