Chapter 1

Introduction

1.1 NLTE Spectrum Synthesis and SNe Ia

It is perhaps fitting, but more likely absolutely necessary, to start off this thesis with a definition of the title – NLTE spectrum synthesis of Type Ia supernovae. NLTE stands for non-local thermodynamic equilibrium. It represents a step up from LTE by accurately solving the rate equations to determine the level populations for a selected set of ionic species. Non-local means that it incorporates effects beyond just that of the the local electron temperature in order to determine the level populations. Given a finite piece of the atmosphere, these effects include both non-thermal ionization due to the local γ-ray deposition and the effects of the impinging radiation field. Spectrum synthesis, in broad terms, is the numerical calculation of a spectrum given a particular model for an atmosphere. A model includes such information as abundances, radial, velocity and density gradients and the overall luminosity of the object. Type Ia supernovae (SNe Ia) are are among the brightest known objects in the universe. They form a nearly homogeneous class and given a simple selection criterion the observed dispersion in their overall luminosity is quite small. They occur in both spirals and ellipticals and the current prevailing wisdom is that they are the explosion of a Chandrasekhar-mass white dwarf. The classification of 'Ia' is a spectral one, based on the absence of hydrogen in the spectra and a prominent Si II feature near 6000Å.

SNe Ia can be thought of as one of the fundamental building blocks in astronomy. The elements they eject are are important for nucleosynthesis studies as they provide a large fraction of a galaxy's metals. In addition, they are valuable distance indicators for cosmology yielding some of the best measurements of both the Hubble constant and the deceleration parameter. The modeling of their atmospheres and spectra provides us with three tools to further our understanding of SNe Ia. First, in comparing synthetic and observed spectra, we are able to ascertain information on the temperature, density, velocity, and composition of the ejected matter. Second, by calculating the spectra of hydrodynamical models of SNe Ia, we are able to constrain both explosion mechanisms and progenitor types. Third, incorporating the spectral fitting expanding atmosphere method (SEAM) one can measure the luminosity of a SN Ia, yielding distances to individual events that are independent of distances based on the decay of ^{56}Ni in SNe Ia and of Cepheid variable stars in the parent galaxies.

This thesis is broken down into 4 major sections, each highlighting a different way with which to use spectrum synthesis to analyze SNe Ia. Chapters 2 and 3 look at normal SNe Ia and their potential use as distance indicators using SEAM. Chapter 4 examines spectral correlations with luminosity in SNe Ia and provides a plausible explanation for these correlations via spectrum synthesis. In Chapter 5 the spectra of various hydrodynamical models are calculated in an effort to answer the question of which current progenitor/explosion model is the most plausible for a SN Ia. Finally, we look at the importance of NLTE calculations and line identifications in Chapter 6. Also included are two appendices which contain more technical information concerning γ-ray deposition and the thermalization parameter.

1.2 Phoenix

All of the spectrum synthesis calculations shown in this thesis use the code PHOENIX to calculate the model atmospheres. The work compiled for this thesis was stretched out over a three year period. During this time PHOENIX has gone through several revisions. PHOENIX 4.8 was used for the work in Chapters 1-4 and in Chapters 5 and 6 PHOENIX 7.1 was incorporated. The following is a general description of the code and the differences between the two versions mentioned above.

PHOENIX 7.1 (Hauschildt, 1992a,b, 1993; Hauschildt, Baron, & Allard, 1996) is a generalized stellar atmosphere code which has been used successfully to produce spectra for novae, all types of SNe, red giants, cool stars and even AGNs. The code accurately solves the fully relativistic radiation transport equation along with the non-LTE rate equations while ensuring radiative equilibrium (energy conservation) (Baron et al., 1995; Hauschildt et al., 1995, 1996). The following ions have been treated in NLTE for type Ia supernovae calculations (the number of levels follows in parenthesis): He I (11), He II (10), Na I (3), Ne I (26), Ca II (87), Mg II (18), C I (228), O I (36), Fe II (617), Co II (255), Ti II (204), S II (85) and Si II (94). In addition, the code is now able to handle the treatment of nebular boundary conditions, as well as a stratified composition and a full γ-ray deposition calculation. This is the major difference between this version and version 4.8 along with putting the iron peak and CNO elements into NLTE.