Calculation of Synthetic Ionizing Spectra for Planetary Nebulae

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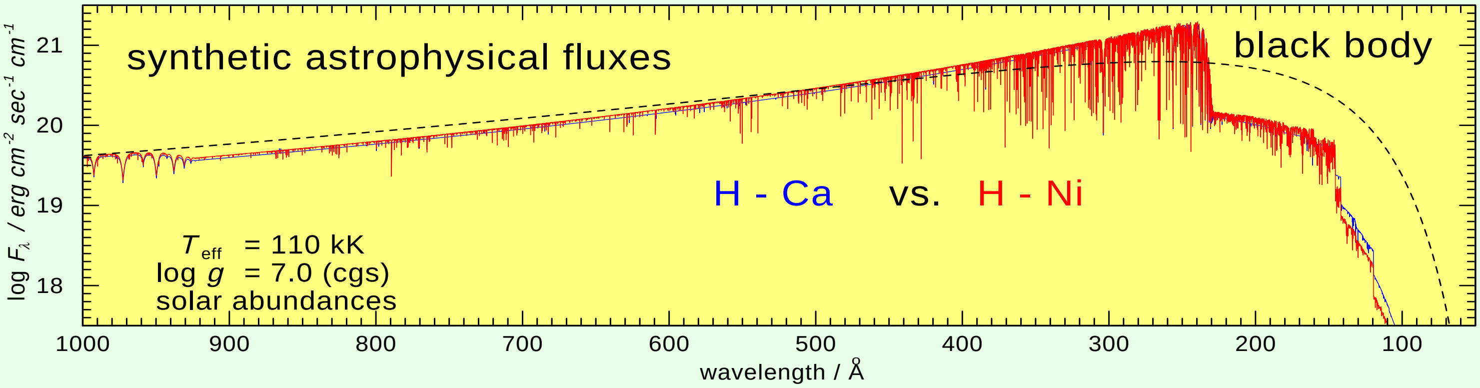

Fig. 1 Comparison of NLTE model atmosphere fluxes with different elemental composition at solar abundances. Note that emergent fluxes calculated from NLTE model atmospheres which include iron-group line blanketing show a drastic decrease of the flux level at high energies.

Abstract

The precise analysis of properties of planetary nebulae is strongly dependent on the ionizing spectrum: Observations as well as NLTE model atmosphere calculations have shown that spectra of their exciting stars neither have something to do with black-body spectra nor can be modeled sufficiently well with "standard" NLTE atmosphere models which are composed out of hydrogen and helium only: Strong differences between synthetic spectra from these compared to the observed spectra at energies higher than 54 eV (He II ground state) can be ascribed to the neglected metal-line blanketing.
For a reliable calculation of the stellar flux as ionizing spectrum for planetary nebulae the consideration of opacities from all elements from hydrogen up to the iron-group elements is required.
The accelerated lambda iteration (ALI) method represents a powerful tool to calculate metal-line blanketed atmospheres with more than 300 atomic levels treated consistently in NLTE. Thus, together with recent atomic data from the Opacity Project and Kurucz's line lists, we can calculate realistic atmospheres with millions of lines included.
We present a new grid (solar and halo abundance ratios) of state-of-the-art fully line-blanketed NLTE model atmospheres which covers the parameter range of central stars of planetary nebulae.

Introduction

During their evolution, central stars of planetary nebulae (CSPN) can reach extremely high effective temperatures (more than 100 kK). Since NLTE effects are particularly important for hot stars, the use of reliable NLTE stellar model atmosphere fluxes is required for an adequate spectral analysis of these stars.
Realistic modeling of the emergent fluxes of these stars requires the consideration of all elements from hydrogen up to the iron group (Armsdorfer et al. 2001).

NLTE Model Atmospheres

- NLTE code **PRO2** (Werner 1986, Werner & Dreizler 1999)
- – plane-parallel
- – hydrostatic equilibrium
- – radiative equilibrium
- → H – Ca (Rauch 1997)
- – more than 300 levels treated in NLTE
- – more than 1 000 lines
- → iron group (Dreizler & Werner 1993, Deetjen et al. 1999)
- – millions of lines Tab. 1

Impact of light metals (F – Ca)

The drastic impact of the light metals (F – Ca) on the emergent flux in the EUV / X-ray wavelength region is shown in Fig. 1 (cf. Rauch 1997).

Iron-group elements (Sc – Ni)

A detailed consideration of all line transitions of the iron-group elements, like tabulated in Kurucz (1996), is impossible for the model structure calculation. Thus, we have employed an opacity sampling method in order to calculate their absorption cross sections.

Cross-sections of iron-group elements

- Cross-Section Creation Package **CSC** (Deetjen 1999)
- → http://astro.uni-tuebingen.de/~deetjen/csc.html
- → line cross-sections
- – radiative und collisional bound-bound
- – Kurucz's line lists (1996)
- – opacity sampling method
- → photoionization cross-sections
- – radiative und collisional bound-free
- – Opacity Project (Seaton 1994) for Fe

The term scheme of the model atom is typically divided into seven energy bands (Haas 1997).

A sample of iron-group elements can be combined in one generic model atom. The statistics of a typical generic model atom are summarized in Tab. 1.

Tab. 1 Summary of a generic Ca-Ni model atom used in our model atmosphere calculations of the 110kK/7.0 model (Fig. 1). Numbers in brackets denote individual levels and lines used in the statistical NLTE line-blanketing approach

element	ion	NLTE levels		line transitions	
generic	IV	7	(30 293)	33	(4 174 474)
	V	7	(20 437)	34	(2 629 792)
	VI	7	(16 062)	36	(1 763 234)
	VII	7	(12 870)	44	(1 244 407)
	VIII	7	(9 144)	36	(821 005)
	IX	7	(12 931)	36	(989 877)
total		42	(101 737)	219	(11 622 789)

Impact of iron-group elements

- H – Ni model
- H – K detailed model atoms
- Ca – Ni in addition, one generic model atom (Tab. 1)
- – all available (experimental + theoretical) Kurucz levels + lines

The impact of the iron-group elements (Sc – Ni) on the model flux is shown in Fig. 1.

Conclusions

- Emergent fluxes calculated from NLTE model atmospheres which include iron-group line blanketing show a drastic decrease of the flux level at high energies.
- For a reliable analysis of extremely hot stars, or the calculation of ionizing spectra from these (e.g. used as input for photoionization models) the consideration of all elements from hydrogen up to the iron group is mandatory.
- In the case of H – Ni models, a detailed consideration of the metal-line blanketing has an important influence on the spectrum.

NLTE Model Fluxes on the WWW

A grid of H – Ca ($T_{\rm eff}$ = 50 – 1 000 kK, log g = 5 – 9 (cgs), solar and halo abundances) and H – Ni ($T_{\rm eff}$ up to 190 kK) model atmosphere fluxes is available at
http://astro.uni-tuebingen.de/~rauch.

Ongoing and future work

- the H – Ni grid is still calculated, models with effective temperatures above 200kK are still missing
- the H – Ni grid will be extended towards lower effective temperature (about 35kK) and lower surface gravity (log g about 4)
- the H – Ca model atoms will be more detailed

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