SMART – a computer program for modelling stellar atmospheres

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1. Introduction

Program SMART (Spectra and Model Atmospheres by Radiative Transfer) has been composed for modelling atmospheres and spectra of hot stars (O, B and A spectral classes) and studying different physical processes in them [1]. Line-blanketed models are computed assuming plane-parallel, static and horizontally homogeneous atmosphere in radiative, hydrostatic and local thermodynamic equilibrium. Main advantages of SMART are its shortness, simplicity, user friendliness and flexibility for study of different physical processes. SMART successfully runs on PC both under Windows and Linux.

2. Main features

* **Model atmospheres** are improved iteratively varying only temperature and pressure dependency on column density. Flux constancy 0.1–0.5 % is achieved by about 10 iterations, using Kurucz ATLAS9 models as input. Number of atmospheric layers can be multiplied up if necessary. Line absorption has been completely taken into account with spectral resolution 300 000.
* **Radiative transfer** calculations give radiative flux $F_\nu(\lambda, \tau)$ in all layers of atmosphere. Radiative transfer has been calculated using integration by parts, yielding series of exponential integrals. The scattering processes are computed by simple Λ-iteration.
* **Programming language** is Fortran 90, program is compiled using Intel Fortran Compiler. Code is extensively commented on right-hand margin.
* **Graphical interface** (in C++) has been composed for visualizing results of calculation.

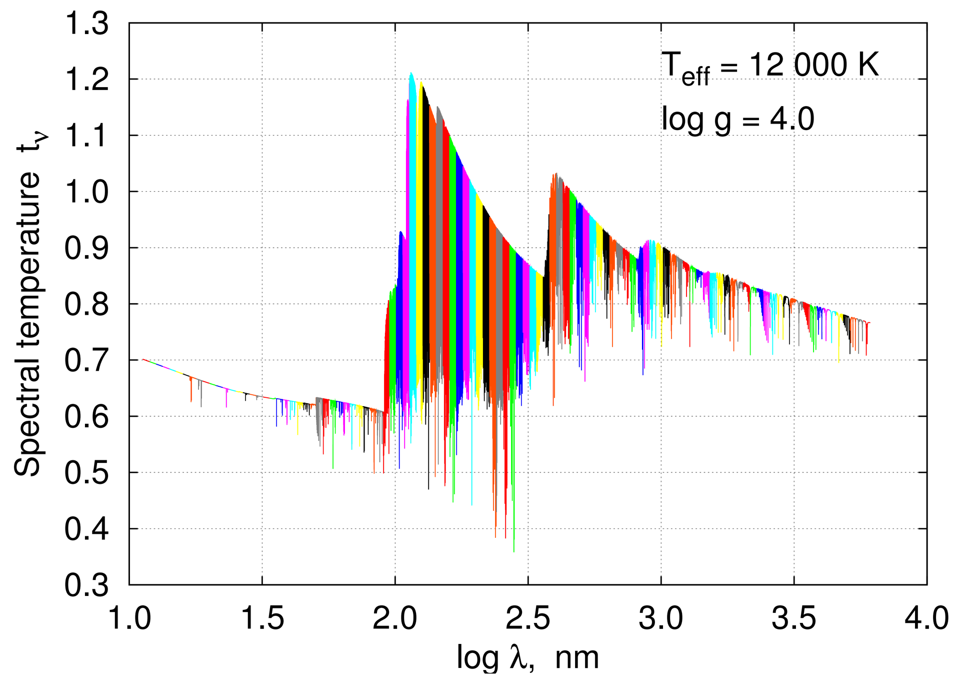

Figure 1: *Synthetic spectrum. Spectral temperature* $t_\nu = T_\nu / T_{\rm eff}$*, where* T_ν *is defined as blackbody temperature corresponding to emergent flux* $F_\nu = B_\nu(T_\nu)$*.*

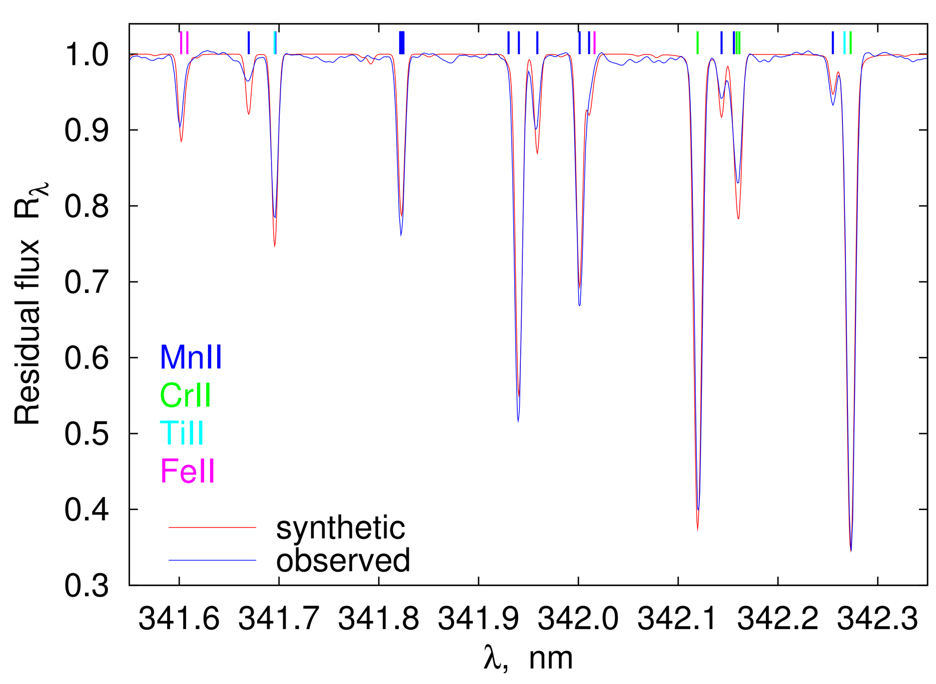

Figure 2: *Observed spectrum of HD175640 by Castelli & Hubrig [2] compared with corresponding synthetic spectrum (*$T_{\rm eff} = 12\,000\ K, \log g = 3.95, V \sin i = 2.5\ km\ s^{-1}$*).*

* **Basic restrictions:** 1D, static, LTE, no convection, no molecular absorption ($T_{\rm eff}$ >9 000 K)
* **Problems reducing accuracy:** multiple light scattering is treated using simple Λ-iterations; instability of algorithms near Eddington limit; incomplete and inaccurate atomic data; simplified treatment of Stark broadening of H and He lines.

3. Special tasks

3.1 Diffusion

SMART enables to compute evolution of chemical composition in atmospheres of CP stars due to diffusive separation of elements and isotopes driven by radiative acceleration, light-induced drift and gravity [3, 4]. High-precision line list and collision cross-sections are necessary. Currently calculations have been made for mercury isotopes, similar calculations for calcium are in preparation.

3.2 Relaxational formation of NLTE

Equilibrium quantum state populations for any ion are found from the equations of unbalanced statistical equilibrium treated as an relaxational initial value problem from LTE to NLTE populations.

3.3 Limb darkening

Detailed spectral limb darkening has been computed for some model stellar atmospheres and used thereafter for finding spectra of rotating stars and non-irradiated eclipsing binaries. Codes accounting also for stellar surface distortion and gravitational darkening are currently prepared.

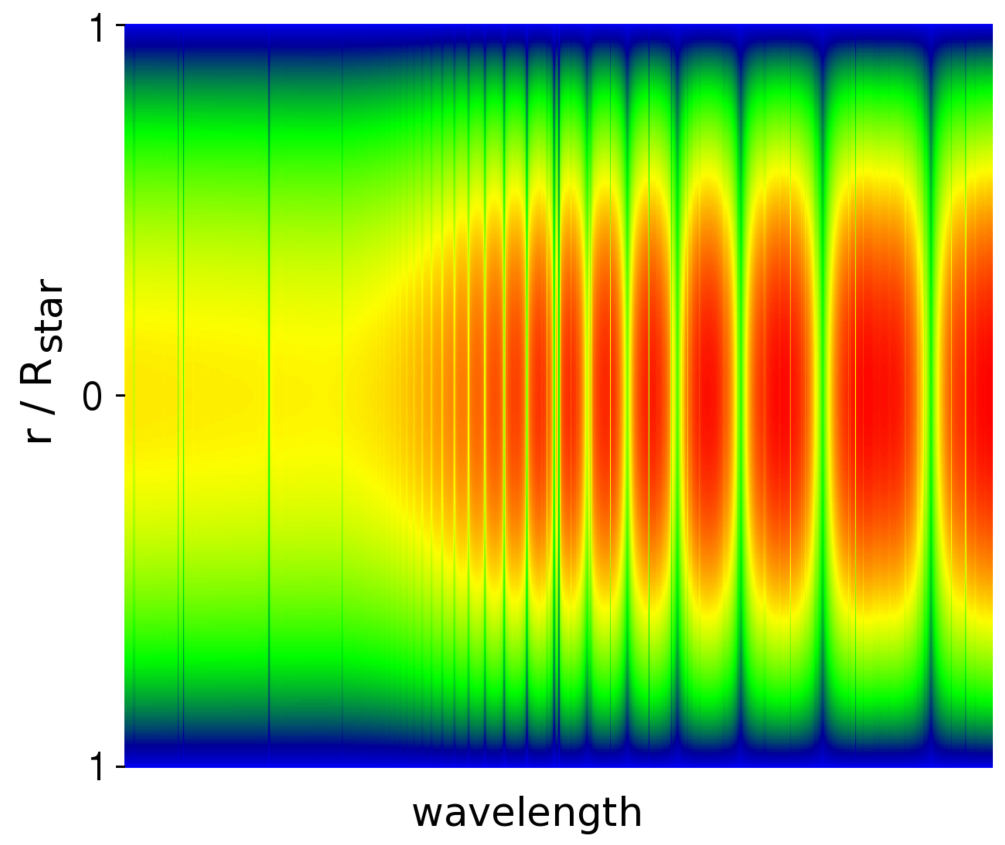

Figure 3: *Limb darkening of a rotating B star near Balmer jump.*

3.4 Acceleration of moving clumps

To enlighten the problem of stellar wind triggering in stellar atmospheres, the radiative acceleration of moving clumps with Doppler shifted spectral lines has been studied and found to give hopeful results.

3.5 Pan-spectral method of abundance determination

Pan-spectral method for determining element abundances [5] is aimed for the automatic processing of high-quality stellar spectra. The method is based on weighted cumulative linewidths Q_λ defined as

$$Q_\lambda = \int_{\lambda_0}^{\lambda} \left| \frac{dR_\lambda}{dZ} \right| (1 - R_\lambda) d\lambda \ ,$$

where R_λ is the residual flux (intensity) and $Z = \log(N_{elem}/N_{tot})$ is the abundance of studied element or isotope. The derivative of residual flux R_λ with respect to abundance Z automatically excludes spectral regions insensitive to changes of the abundance of studied element and gives a large contribution in the most sensitive regions, i. e. in the centers of non-saturated lines and in the steep wings of strong lines of the element. Best fit of quantities Q_λ found from synthetic and observed spectra gives final abundance taking duly into account all lines of studied element including blended ones. Abundances can be found simultaneously for many elements. The method has been implemented as an extension to SMART. It can also be used to find corrections of effective temperature and gravity.

4. General structure of the code

- Introductory part
  - Read in program control specifiers;
  - Read in atomic and model data and process them according to the present task;
  - Compute ionization rates and partition functions (subroutine SAHA). Diffusion coefficients are also computed here;
  - Read in and process line data;
  - Read in continua data.
- Main calculations
  - Compute continuous absorption coefficients;
  - Compute absorption in lines;
  - Compute radiative transfer and find flux in all layers of the atmosphere (subroutine SPECTRUM).
- Task modules
  - Model corrections;
  - Diffusion of elements and isotopes;
  - Relaxational formation of NLTE;
  - Limb darkening;
  - Acceleration of moving clumps.
- Output part

Typical running times

On a PC with CPU 3.2 GHz and 2 GB RAM

* Model atmosphere computation with spectral resolution 300 000 and 64 layers of atmosphere takes several hours.
* One time step in evolutionary computations of separation of mercury isotopes in atmospheres of CP stars with resolution 5 000 000 takes approximately 15 min.

5. Final remarks

SMART is simple and handy computer code for study of hot stellar atmospheres, their spectra and different physical processes in them using capabilities of typical modern personal computers, being thus suitable for wide use.

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References

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