D3 - Spectral analysis of a Wolf-Rayet star

Task

Determine the temperature T_*, radius R_*, luminosity L, mass loss rate $\dot{M}$, the mass fraction of hydrogen X_{H}, and the stellar wind's terminal velocity v_{∞} of the Wolf-Rayet star BAT99 58 (Brey 47) in the Large Magellanic Cloud (LMC) by comparison with synthetic spectra calculated with the PoWR stellar atmosphere code.

General

As you already learnt in D2 (Determine the mass loss rate of OB stars), hot and massive stars have strong mass loss by stellar winds. This can be seen in their spectra that, in case of the Wolf-Rayet (WR) stars, are entirely dominated by emission lines formed in the wind. These stars are seen as late evolutionary stages of very massive O-type stars that might be at the transition between (central) hydrogen and helium burning.

To derive stellar parameters, the observed spectrum is compared to model spectra (synthetic spectra). By means of the Potsdam models of expanding stellar atmospheres (PoWR) one can analyze spectra of hot stars ($T_* > 10\,\mathrm{kK}$), which holds true for WR stars. According to the dominance of nitrogen or carbon lines in the spectrum a distinction is made between WR stars of the nitrogen (WN) and carbon (WC) sequence, while the former are subdivided into **late types** (WNL) and **early types** (WNE) depending on their atmosphere's hydrogen content. In this experiment a WN type star of the LMC shall be examined.

Preparation

Find the grid models at the main page of the Astrophysics Department of the Uni Potsdam. Get an impression of the parameters that enter into the models, e.g. the range of temperatures and the so called transformed radius R_{t}. Learn the principles of line-driven winds. Then copy the *WRplot* script `lmcstars.plot` and the accompanying file for the line identifications `ident.dat` from the directory `~/scripts/d3/` into your working directory on the laboratory course computer `columba`.

Realization

Observational data

There are visual observational data for the star that are already linked in the previously mentioned *WRplot* script. Additional UV observations from the International Ultraviolet Explorer (IUE) can be downloaded from the *MAST* archive. There are spectra in different wavelength ranges (SWP: $1150-1980\,\unicode{x212B}$ and LWP or LWR: $1850-3350\,\unicode{x212B}$). Search in the

MAST archive for UV data of this star (note: the search radius should be limited to a few arcseconds) and save the downloaded fits files in your working directory. To ease the further handling, convert the fits files (the spectra) to X-Y tables (ASCII format), e.g. with the program *fitsview*:

```
fv filename.fits
```

Display all data tables by clicking on `Table` and then `All`. Mark and delete unneeded datasets and export the remaining data as a text file (choose a descriptive filename) with fixed column width. Add the reference number of the selected observation as comment line (starting with an asterisk, *). Alternatively, search for the star directly in the IUE database. On the results page, click on the `Data ID` to get to the preview window, where you can download the spectra as ASCII files.

Furthermore, use *Simbad* and *VizieR* to obtain the photometry of the star. This means the u, b, and v small band magnitudes (Smith et al. 1968) as well as the 2MASS IR broad band magnitudes (J, K, and H). Copy these values to the *WRplot* script. If needed look for photometry in the literature.

Fit the spectrum

In principle the *WRplot* script can be used right away, just some variables and parameters (those that are seeded with q ?) need to be specified. Choose a model and the corresponding grid, copy the values for the photometry and enter the path of the observational data. Create the so-called masterplot by running the script

```
wrpdf lmcstars.plot
```

which creates the file `lmcstars.pdf`. It contains five panels and a headline with information on the model, its temperature, radius, velocity, abundances, and the model number. The uppermost panel shows the spectral energy distribution (SED) in a double logarithmic plot (absolute flux over wavelength). The observation is in blue, the chosen model in red, the blue boxes mark the photometry. The other panels show the normalized line spectrum (flux over wavelength) in the same color coding.

The task is to select the model that shows the best possible accordance with the observed spectrum. Pay attention to the identified spectral lines: Their form, height, and width should be reproduced by the model spectrum. By changing the model number (variable `MODEL`), the temperature (the first two digits of the model number) and/or the transformed radius (the last two digits of the model number) can be changed. First check if the hydrogen lines $\mathrm{H_{\alpha}}$, $\mathrm{H_{\beta}}$, and $\mathrm{H_{\gamma}}$ can (roughly) be reproduced. If the hydrogen lines are very different, change the grid. For the LMC there are three model grids available that differ in their hydrogen content (and their helium content, thus): 40, 20, 0% hydrogen mass fraction. Change between the model grids by setting the appropriate path (variable PATH):

WNs with 40% hydrogen (WNL)	`~/scripts/d3/models/wnl40/`
WNs with 20% hydrogen (WNL)	`~/scripts/d3/models/wnl20/`
WNs without hydrogen (WNE)	`~/scripts/d3/models/wne/`

For some standard grid models, additional versions with different wind velocities (v_{inf}) are available. Once a model has been found that reproduces the normalized line spectrum continue with the SED fit. For this purpose, adjust the reddening (variable EBVSMITH) and apply a shift to the luminosity (variable `shift`). Their starting values could be `shift=0` and `EBVSMITH=0.1`. The line strength of the normalized emission spectrum depends on the temperature and the transformed radius, so the luminosity can be scaled up/down in a certain interval by means of the `shift` variable without affecting the normalized spectrum. The model SED should reproduce the general trend of the observations, while going through the center of the photometry boxes. This ensures a correct model flux.

Determine the stellar parameters

The stellar parameters can be obtained from the properties of the selected model. These parameters are described on the PoWR homepage. Following the Stefan-Boltzmann law:

$L \propto R_{*}^2$ and $L \propto T^4$,

both combined:

$L \propto R_{*}^2 \cdot T^4$.

The stellar radius (at constant luminosity) is proportional to T^{-2}. By adding the `shift` parameter to the luminosity, the model luminosity can be adjusted to the true luminosity of a star.

The mass loss rate is connected to the luminosity via the transformed radius:

$R_t \propto \dot{M}^{-\frac{2}{3}}$ and $R_t \propto R_{*}$

$\Rightarrow \dot{M} \propto L^{-\frac{3}{4}}$.

So, in total: $\dot{M}^{\frac{2}{3}} \propto T^{-2} \cdot R_t$.

Report

A usual laboratory course report is to be handed in.

Overview: Laboratory Courses