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 PoWR models.

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 which are, in case of the Wolf-Rayet (WR) stars, entirely dominated by emission lines that form in the wind. These stars are seen as late evolutionary stages of very massive O-type stars that may be at the transition between (central) hydrogen and helium burning.

To derive stellar parameters from the observed spectrum they are compared to model spectra (synthetic spectra). With help of Potsdam Models of expanding stellar atmospheres (PoWR) 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 with nitrogen (WN) and carbon (WC), 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 `~/skripte/d3/` to the laboratory course computer a12 into your working directory.

Course

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 $\mathrm{\AA}$ and LWP or LWR: 1850–3350 $\mathrm{\AA}$). 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, text files), e.g. with the program fitsviewer:

```
fv filename.fits
```

and display all data tables (Table → All). Mark and delete unneeded datasets and export the remaining data as 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, download the IUE spectra directly from the IUE database. Search for the star and the results page will display the spectra and allow to download the spectra as ASCII files.

Furthermore, use Simbad and VizieR to obtain the photometry of the star. This means the u, v and b small band magnitudes (Smith et al. 1968) as well as the 2MASS IR broad band magnitudes (J, K and H). Copy these values. 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 need to be set (so far they are set "= ?"). 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 (as PDF file) 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 between the observed and model spectrum. Mainly 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`) change the temperature (the first part of the model number) and/or the transformed radius (the second part). 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% H (WNL)	`~praktikum/skripte/d3/models/wnl40/`
WNs with 20% H (WNL)	`~praktikum/skripte/d3/models/wnl20/`
WNs without H (WNE)	`~praktikum/skripte/d3/models/wne/`

Some standard grid models have different versions with different wind velocities (v_{inf}) available. Once a model has been found that reproduces the normalized line spectrum start with the SED. To fit the SED change the reddening (variable `EBVSMITH`) and shift in 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 help of the `shift` variable without changing the spectrum. The model SED should reproduce the general distribution of the observations while going through the center of the photometry boxes. This ensures the correct flux distribution for the model.

Determine the stellar parameters

The stellar parameters can be obtained from the information 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 true luminosity can be customized for 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: $\dot{M}^{\frac{2}{3}} \propto T^{-2} \cdot R_t$.

Evaluation

A usual laboratory course protocol is to be handed in.

Overview: Laboratory Courses