Astrophysics Lab Work – Computational Basics – Fortran

This exercise will help you to become acquainted with some basic features of `Linux`, `gnuplot`, `IDL` and `Fortran`, in order to be able to solve the problems involving computational aspects in the various parts of your lab work.

Regarding this exercise, **please work alone** (not in groups), since otherwise you will learn much less. Copying from other solutions will not be tolerated!

Preliminary remarks. The exercise itself can be performed either

i) **recommended**: on your own computer, by connecting with the `numprakt` accounts of some of the instute's machines (`ltsp04 ... ltsp17`) via `tigervnc` with active `eduVPN` tunnel.
NOTE: if your machine is "busy" (other users already logged in), try another machine. Try to work always on the same machine. If this is not possible, copy (via scp) your working directory (see Exercise 1) from your former machine to the currently used one.

ii) on your own computer, if you have LINUX installed (either directly, or as a virtual system), and a working internet connection. To connect to our numprakt-machines, the `eduVPN` tunnel must be active.

iii) on your own computer under any operation system, when you have an X-server running and can connect to the hosts according to i) via `ssh`. To connect to our numprakt-machines, the `eduVPN` tunnel must be active.

Passwords and machine/session numbers have been provided to you in the "intro"-lab.

In your write-up, describe briefly all tasks and provide/discuss your results. Do not forget to include all plots (as `.ps` files), `gnuplot` scripts, F90-programmes, and IDL-procedures. Please provide always figures in `.ps` format, and **not** as screenshots.

To work most efficiently, always have at least two windows open, one to edit the F90-program or gnuplot/IDL-procedure (`emacs` *progname* `&`), and the other one for testing/running the program/procedure. Don't forget to save your modifications to disk (`CTRL x CTRL s` in emacs) and to recompile the code (`ifort ...`, `.run` *procedure*, `load` *gnuplot-script*, respectively) before testing them.

Make extensive use of the various help-files (pdf-format) contained in the introductory section of our home page, as well as of the gnuplot and idl help system.

Don't be shy to test various possibilities. The most effective way to learn about a certain device is to play, play and play with it!!! (At least with respect to computers.)

In addition to your write up, **please log all your commands from exercise 1 to a file `YourName_logfile.txt`. Log only successful commands!**

Collect all files (write-up, logfile, ps-files, programmes and scripts), create a corresponding `gzipped tar`-file, `YourName_ex.tgz`, and drop this file into the assigned storage-space.

Exercise 1 – Files and directories

Please log all commands (see above)

- Login to your home directory or to numprakt on the appropriate USM-host (see above).
- Create a directory called YourName, where YourName should be replaced by your actual name. This will be your working directory. Please perform all following exercises (1 to 3) inside this directory!!!!
- In this directory, create a subdirectory Europe.
- Within this directory, create two subdirectories called Germany and Italy.
- Change to Germany and create the (empty) files Roma_I Freiburg_D Milano_I Salzburg_A Berlin_D Hamburg_D Ingolstadt_D and Wien_A.
- Move all files containing an I in their names to the directory Italy.
- Delete all files (within Germany) which contain a burg in their names.
- Rename file Wien_A to Stuttgart_D.
- Enter directory Italy and copy all files ending with _D to directory Germany.
- Delete all files which contain a _D.

Include the directory Europe in your final .tgz file.

Exercise 2 – Regression via gnuplot

In this exercise, you will derive the so-called *wind-momentum luminosity relation* (WLR) for Galactic supergiants, which relates the momenta of their radiation driven winds, modified by the sqrt of their radii, with their luminosity. To this end, proceed as follows:

- Copy, via scp, the file public/wlr.dat on numprakt@ltsp08.usm.uni-muenchen.de to your working directory, under name my_wlr.dat, and open it with emacs. The table contains (among other info) the following information about a sample of Galactic O-stars:
  1. Name, identifed by HD number (Henry-Draper catalogue),
  2. lc, luminosity class,
  3. Teff (effective temperature), in units of 1000 K,
  4. Rstar (stellar radius), in units of solar radius,
  5. vinf (terminal velocity of stellar wind), in units of km/s,
  6. Mdot (mass-loss rate of stellar wind), in units of 10^{-6} solar masses per year.
- Within the table, comment all entries with l.c.$\neq$1 by inserting a hash # at the beginning of the corresponding lines. (The hash is the comment sign for shell scripts and gnuplot). In this way, only data for lc=1 objects (supergiants) will be processed by gnuplot.

- As a first test, plot radius as a function of Teff for the Galactic O-supergiants via `gnuplot`. Convince yourself that the correct number of objects are plotted. Save the `ps`-version of this plot under `ostars.ps` (inspect it via `gv`).

In the following, you will calculate and plot the modified wind momenta of the stars as a function of their luminosity ($\log - \log$ plot, data from file `my_wlr.dat`), and overplot a corresponding linear regression. The result will display the WLR for Galactic supergiants.

- Work with two windows in parallel: one for `gnuplot`, where you can test your solution, and one for `emacs`, where you create and modify a corresponding `gnuplot`-script, which should be named as `my_wlr.gpl`.
- By means of this script, plot the modified wind-momenta read and calculated from file `my_wlr.dat` as a function of luminosity as symbols, i.e., plot $\log_{10} D_{\rm mom}$ as a function of $\log_{10} L/L_\odot$, where

$$\begin{aligned} D_{\rm mom} &= \dot{M} \cdot v_{\rm inf} \sqrt{R_{\rm star}/R_\odot} \\ L/L_\odot &= (R_{\rm star}/R_\odot)^2 \cdot (T_{\rm eff}/T_{\rm eff,\odot})^4 \end{aligned}$$

  with $T_{\rm eff,\odot}$ the solar effective temperature, 5777 K. Calculate $D_{\rm mom}$ by providing $\dot{M}$ in units of $10^{-6} M_\odot/yr$ and $v_{\rm inf}$ in units of km/s.
- Perform a linear fit to the (log-log) data, $f(x) = ax + b$, and overplot the linear regression.
- From these results, write down the WLR for Galactic supergiants (i.e, $\log D_{\rm mom} =$?) within your write-up.
- Finally, add a *meaningful* title, axis-labels and legend.
- Plot the corresponding figure as a `ps file`, and inspect this file via `gv`.

Add the files `my_wlr.dat`, `my_wlr.gpl`, and `my_wlr.ps` to your final `.tgz`-file.

Exercise 3 – IDL and F90 programming

On our homepage (intro-section), you will find the idl-procedure *gamow.pro*, which can be used to display the "Gamow-peak" as a function of various parameters.

Remember that only the actual presence of this peak allows for nuclear fusion in stellar cores (and shells), and results from the competition of the Maxwellian velocity distribution of the colliding particles

$$p(E_{\rm kin}) \propto \exp(-E_{\rm kin}/kT_{\rm plasma}),$$

and the probability to tunnel the Coulomb wall between two charged particles,

$$p(E_{\rm kin}) \propto \exp(-b/\sqrt{E_{\rm kin}}),$$

where b is defined, e.g., inside the procedure. In particular, *gamow.pro* displays the individual probabilities (without leading factors) and the combined probability, as a function of the particles' kinetic energy in units of $kT_{\rm plasma}$.

a) Study the procedure carefully and try to understand *each* statement, in particular the way how the x-grid is initialized (in a very effective way). Note also the way idl handles the arrays (without explicitly declaring them).
The units of the Boltzmann-constant are given in `cgs`. Which changes would have to be performed if this quantity was given in `SI` units?

b) Play around with the procedure and try to find the plasma temperature where the Gamow peak

1. for proton-proton collisions

2. for He-He collisions

is located at 10^{-10} (in the units used here, i.e., discarding leading factors), which should give you a fair guess about the required temperatures to start the corresponding fusion processes. Create meaningful plots.

c) Write an analogous Fortran 90 program for the first lines of *gamow.pro* calculating the various probabilites (including the line which defines "ptot"), using only the default values for the colliding particles. Within the program, `write` the energy grid and all three probabilities into a file (one line per `kt, p1(kt),p2(kt),ptot(kt)`).

Use the programs given in the F90 manual (homepage!) as an example.

Modify the idl procedure in such a way that the above quantities (`kt, p1(kt), ...`) are printed out within idl, and compare with the content of the F90 output file. Improve your program until the results are the same (to within the chosen precision).

Add your programs, `.ps`-files and IDL-scripts to your final `.tgz` file. Don't forget to summarize your tasks and results in your write-up.

Have a lot of fun.