Stellar Atmospheres, Ht 2002
Lab 1: Spectral Line Formation

Lab report due: Tuesday, 22 October 2002

1 Literature

The following sections in your course texts may be helpful in understanding this lab.

- D. F. Gray, *The observation and analysis of stellar photospheres* (1992): pp. 202–209 on the line absorption coefficient, pp. 225–229 on Doppler width and Voigt function, chapter 13 on the behavior of spectral lines, and pp. 27–30 on convolutions.
- R. J. Rutten, *Radiative Transfer in Stellar Atmospheres*: parts of 3.3; 4.2.1; "surface values" in 4.3.2; 7.3.1; and 8.2.

2 Introduction

This computer exercise is a continuation of last semester's exercise on line formation in a homogeneous slab. Here, you will study spectral line formation in a one-dimensional model atmosphere. You will use a computer program that allows you to vary the parameters that determine the emergent line profile. The Voigt profile (the absorption profile of the spectral line), the total opacity and the source function are plotted together with the emergent intensity of the line, which is given by:

$$I_\nu^+(\tau_\nu = 0, \mu) \;=\; \int_0^\infty S_\nu(t_\nu) e^{-t_\nu/\mu}\, dt_\nu/\mu \qquad (1)$$

The idea is to play around with the interactive software and to write a report on radiative transfer and line formation. The questions in this text are offered as a guide for writing your report.

3 Procedure

The programs are written in the IDL programming language. After logging on with your user name and password, go to a terminal window (or open one, e.g., by right-clicking on the workspace background and choosing "Hosts/This Host" from the pull-down menu). Then type

```
cd /u1/local/lab/stjarnatmos/Lab1
idl
```

to start IDL. If you have any problems, the README file in the Lab1 directory describes a couple of things you can try before asking for help.

Once you have launched IDL, you can start this computer exercise by typing the command `xtransp`. The program uses sliders to change the values of the different variables, which are explained very briefly in a window invoked by the `Help` button. Later, for the lab report, you may want to use the `Print` button to save screen output as a Postscript file in your home directory; you will be asked to type the file name in the terminal window from which you started IDL. To quit the program, press the `Done` button, then type `exit` to quit IDL.

4 Line Formation

The five variables of interest here are: the Voigt damping parameter `a` which determines the shape and maximum value of the Voigt function; the continuous and line opacities relative to the continuum absorption coefficient at the reference wavelength 500 nm; the cosine μ of the angle between the ray and the normal of the atmosphere; and the plot range on the x-axis in units of the number of Doppler widths from the line center.

The `Source` button enables you to choose between two different source functions S_ν, one for LTE and one for the calcium line. Give an explanation of the different parameters and what you see in the different panels. When working on the questions below, draw what you see and write down important values. Pay attention to the automatic scales.

Begin by playing around to get the feeling for the different parameters. For example, choose `xmax`$= 20$ and `mu`$= 1$. How is `xmax` defined, and which part of the Sun are you observing with this value of `mu`?

1. Explore the damping constant. Explain what a Voigt profile is and how its maximum and its shape are determined by the damping constant a. What kind of profile results for small and large values of a? When you are finished with this section, set the damping constant to $\log a = -3$.

2. Explore the extinction coefficient.

   (a) How are the damping profile and the extinction coefficient related? What does the extinction-coefficient profile look like for large and for small line opacities? Try to explain why the extinction coefficient appears different in the two cases.

   (b) What happens if you increase the continuous opacity? Examine different cases by varying the line and continuous opacities. How does the line opacity and the continuous opacity relate to the emergent profile for weak lines, assuming Eddington-Barbier? What is a weak line?

3. Explore the emergent line profile in the LTE case. In the following, you can keep the damping constant, the continuous opacity $\log(\alpha_c/\alpha_{500}) = 0$ and `xmax` constant.

   (a) Set the continuous opacity ratio to $\log(\alpha_c/\alpha_{500}) = 0$. Explain what you see in the different panels (such as the value of $\alpha_{\text{tot}}/\alpha_{500}$ and the values of $\tau \equiv \tau_{tot}$ and τ_c). Calculate the expected values of the optical depths. Are the relations the same for any $\alpha_c/\alpha_{500} = \alpha_\ell/\alpha_{500}$?

   (b) What happens if you increase the line opacity moderately? Why? What does increasing α_ℓ correspond to physically?

   (c) Increase the line opacity even more. Do so until an emission peak appears. What is happening? Try to explain the situation with the Eddington-Barbier approximation. When is this approximation valid? What would you expect according to Eddington-Barbier? See what happens if you put $\tau_{tot} = 1$ (the unit optical depth in the line) in the minimum of the source function. Are there other, more correct ways of explaining it?

   (d) Can you manipulate the opacities in order to get

      i. a pure emission line?

      ii. an emission line with absorption in the center, i.e. the opposite situation to the one above?

4. Explore the the emergent line profile in the Ca case. Change to the source function to the one for the calcium line. Also in the following, you should let the damping constant and `xmax` be constant. Start off by putting $\log(\alpha_c/\alpha_{500})$=0.

   (a) Let the line opacity grow. What happens? Did you expect that? Give an explanation. Can one observe this phenomenon in reality? Give an example.

   (b) Repeat the performance but for fundamentally different values of the continuous opacity. How many different cases can you find?

   (c) Can you manipulate the opacities in order to get

      i. a pure emission line?

      ii. an emission line with absorption in the center, i.e. the opposite situation to the one above?

5. Discuss the source function. Give a qualitative explanation for the LTE source function. Compare it to the source function for the calcium line. What is the difference? Why?

6. Explore the μ-dependence of the spectral line. Can you explain limb darkening?

7. Summarize what you have learned about how absorption and emission lines are formed.

5 Report

A written report is required. It should contain a description of what you have been investigating and the results you obtained, both in text and pictures. You should answer as many of the questions in this text as you can, but please feel free to discuss what points were unclear, pose your own questions, and elaborate on any other things you learned.

This computer exercise was adapted from the one written by Nils Ryde, Uppsala Astronomical Observatory, September 15, 1995. The software was developed by Mats Carlsson and Oivind Wikstol at Institutt for Astrofysikk in Oslo. Minor additions were made by Michelle Mizuno. We would appreciate your comments/suggestions on this laboratory exercise in order to improve it further.