ASTR-3415: Astrophysics
Course Computer Project

Dr. Donald G. Luttermoser

East Tennessee State University

Spring 2003

1 Introduction

Your Computer Class Project for ASTR-3415 *Astrophysics* will involve analyzing synthetic spectra generated by the ATLAS LTE stellar atmospheres code originally written by Dr. Robert Kurucz of the Center for Astrophysics at Harvard University (see Kurucz 1979, *Astrophysical Journal Supplement*, volume 40, page 1 for details on the ATLAS code). To assist you in your analysis, I have written an IDL software package called atanalyze.pro. This routine will have the capabilities of calculating continuum fluxes, line fluxes, integrated line fluxes, full-width at half-maximas (FWHM), and equivalent widths of select absorption lines built into the code from the synthetic spectra.

This document describes how to access and run the IDL procedure and how to access the data. The data consists of three files: the *spectrum* file, the *long output* file, and the *opacity* data file. You will be analyzing a series a models to investigate the effects of temperature, luminosity, and abundance on stellar spectra. The final part of this document discusses the analysis I expect you to do and the format of the final report that you will be required to turn in. A sample LaTeX template file will be supplied to you on the Course Project home web page (see below). Please note that this paper is due on **Tuesday, April 10, 2003**.

ATLAS is a code written in Fortran 77 (as most of the large scientific computer codes are) that is designed to model radiative equilibrium stellar atmospheres and to generate LTE synthetic spectra. There are a grand total of 12 synthetic spectra from atmospheric models listed in the table below. Note that ATLAS uses cgs units in its calculations. For these parameters, g is the surface gravity of the star in cm/s^2. Effectively, the $\log g = 1.0$ models will correspond to giant (possibly bright giant) stars and the $\log g = 4.5$ to main sequence stars. For the metalicities, solar abundances correspond to Population I stars, 1% (0.01 = E-2) solar correspond to Population II stars, and 0.01% (0.0001 = E-4) solar metalicity corresponds to stars that would have existed in the very early Universe.

Stellar Model Characteristics

T_{eff} (K)	$\log g$ (g in cm/s^2)	**Metalicity** (Solar = 1.00)	**Run Version Number**
4000	1.0	1.00	1
4000	1.0	0.01	2
4000	1.0	0.0001	3
4000	4.5	1.00	1
4000	4.5	0.01	2
4000	4.5	0.0001	3
7000	4.5	1.00	1
7000	4.5	0.01	2
7000	4.5	0.0001	3

2 Downloading the Files

All of the files for this project can be downloaded from the Course Project web homepage:

http://www.etsu.edu/physics/lutter/courses/astr3415/atlas/project.htm

which also can be accessed from the course homepage. The file listings below, the "Run" parameters are effective temperature/log surface gravity/metalicity as described in the table on the previous page.

The Model Data Files

m4000g10.out.1:	Long output file for Run: 4000/1.0/1.00
m4000g10.opc.1:	Opacity file for Run: 4000/1.0/1.00
m4000g10.spc.1:	Synthetic spectrum file for Run: 4000/1.0/1.00
m4000g10.out.2:	Long output file for Run: 4000/1.0/0.01
m4000g10.opc.2:	Opacity file for Run: 4000/1.0/0.01
m4000g10.spc.2:	Synthetic spectrum file for Run: 4000/1.0/0.01
m4000g10.out.3:	Long output file for Run: 4000/1.0/0.0001
m4000g10.opc.3:	Opacity file for Run: 4000/1.0/0.0001
m4000g10.spc.3:	Synthetic spectrum file for Run: 4000/1.0/0.0001
m4000g45.out.1:	Long output file for Run: 4000/4.5/1.00
m4000g45.opc.1:	Opacity file for Run: 4000/4.5/1.00
m4000g45.spc.1:	Synthetic spectrum file for Run: 4000/4.5/1.00
m4000g45.out.2:	Long output file for Run: 4000/4.5/0.01
m4000g45.opc.2:	Opacity file for Run: 4000/4.5/0.01
m4000g45.spc.2:	Synthetic spectrum file for Run: 4000/4.5/0.01
m4000g45.out.3:	Long output file for Run: 4000/4.5/0.0001
m4000g45.opc.3:	Opacity file for Run: 4000/4.5/0.0001
m4000g45.spc.3:	Synthetic spectrum file for Run: 4000/4.5/0.0001
m7000g45.out.1:	Long output file for Run: 7000/4.5/1.00
m7000g45.opc.1:	Opacity file for Run: 7000/4.5/1.00
m7000g45.spc.1:	Synthetic spectrum file for Run: 7000/4.5/1.00
m7000g45.out.2:	Long output file for Run: 7000/4.5/0.01
m7000g45.opc.2:	Opacity file for Run: 7000/4.5/0.01
m7000g45.spc.2:	Synthetic spectrum file for Run: 7000/4.5/0.01
m7000g45.out.3:	Long output file for Run: 7000/4.5/0.0001
m7000g45.opc.3:	Opacity file for Run: 7000/4.5/0.0001
m7000g45.spc.3:	Synthetic spectrum file for Run: 7000/4.5/0.0001

IDL Procedures

atanalyze.pro:	IDL analysis package.
air2vac.pro:	Convert air wavelengths to vacuum wavelengths.
axiscale.pro:	Create scale factors and labels for the plots. Called by atanalyze.pro.
vac2air.pro:	Convert vacuum wavelengths to air wavelengths. Called by atanalyze.pro.
valid_num.pro	Make sure a string is an actual number. Called by atanalyze.pro.

Additional Files

a3415rep.tex:	A sample LaTeX file (written in LaTeX2e).
a3415fig1.eps:	An encapsulated postscript file used in a3415rep.tex.
compproj.pdf:	PDF version of this document.
compproj.ps:	Postscript version of this document.

Clicking on each link should bring up a text box on your web browser. Once this comes up, select the "Save" menu item under the "File" menu item on your web browser toolbar. If you are running this on a PC, chose a directory location that is specific to you.

The IDL procedure I have supplied to you is written specifically to read and plot information from both the ".spc" file and the ".out" file. You can answer questions concerning opacities as a function of depth from the ".opc" file, and just about anything else you will need to know for your analysis can be obtained from the ".out" file. One final note, I have used IDL Version 4.0 in developing this software. However, I have tested it under IDL Version 5.5 on the PCs in Brown Hall 264 and it works fine. Please note that if you run this with IDL versions earlier than 5.2, you will need some additional procedures I have written that emulates IDL commands that are standard in IDL V5.2 and later (*i.e.*, the "DIALOG" commands). Please contact me if you need these procedures sent to you.

Do not under any circumstances print out any of the files. They are very big and will waste a lot of paper! Instead view them with an editor on your terminal screen.

3 The ATLAS Runs

ATLAS solves the radiative transfer equation from a technique known as lambda-iteration. It assumes that all line source functions are given by the Planck function. The same is the case for the continuous opacities except for the continuous scattering opacities (see the long output for details). In the runs you will be analyzing, all of the continuous opacities that are needed for a given spectral type are turned on. As well, an internal line opacity routine has been turned on which calculates strong lines from neutral and singly-ionized metals, Fe I lines, Fe II lines, and all of the hydrogen lines. However, the line opacities from the "haze" of the 40 million Kurucz line list have not been turned on. This will make things easier on you during your analysis.

You will not have to manually inspect the synthetic spectrum (.spc) file. However, on occasion, you may have to look at the long output (.out) file. Finally, you will have to answer questions about data that is only in the opacity (.opc) file. In this file, selected wavelengths have detailed information printed out about the optical depth, opacity, mean intensity, and source function for all "non-zero" opacity sources at that wavelength. Note that the wavelengths in all of these files are vacuum wavelengths. Your IDL procedure atanalyze.pro automatically converts these wavelengths to air wavelengths when you run it. You can manually convert air wavelengths to vacuum wavelengths with the air2vac.pro IDL procedure supplied to you on the web page. Finally note that in the .opc file, "Resonance Lines" opacities are those strong lines (not including Fe I, Fe II, nor H lines) calculated internally in the LINOP subroutine of ATLAS.

4 Running the IDL ATLAS Analysis Package

If you are running IDL on the Ultra 5 Workstation in Brown Hall 260, change directories to the location you downloaded the files from the Course Project home page, then run IDL at the Unix prompt. Once the IDL> prompt appears, type the following command: atanalyze, datadir='*the directory location of your data*'. Then just follow the instructions in §5 and those in the message box of the IDL GUI widget.

If you are running IDL on the PCs in Brown Hall 264, double click on the IDL icon. Once IDL starts, select "Preference" from the "File" menu item on the toolbar and enter the location of your data and procedures in the "Working Directory" box. Then, select "Open" from the "File" icon and look for and open the atanalyze procedure. Click the compile button, then the run button and follow the directions in §5 and those in the message box of the IDL GUI widget. Note that this text box does not automatically scroll down when new text is displayed as it does with IDL on Unix. Before doing anything, use the scroll bar on the top left text box to read the entire set of directions. As you complete different aspects of the analysis, new messages will be printed to this box. If you notice the scroll bar moving (without seeing new text being printed), move the scroll bar to view the new messages.

Please note that once both data (.spc and .out) files have been read in (you will see check marks after the "Load Data" button), you can print the plots at any time by clicking the appropriate buttons under the plot windows. On Unix systems, the plot is saved in a postscript file and then this file is sent to the printer with the IDL SPAWN command. In the Microsoft environment, the plot is directly sent to the printer without making a hardcopy file. Note that you have the option of making encapsulated postscript files (for inclusion into your LaTeX manuscript) by clicking on the "Encaps Plot" button before making the plot. Your file will then have an ".eps" filename suffix instead of the normal ".ps" standard postscript suffix. Note that encapsulated postscript files can be made on either the Unix or the Windows environments. Margins on the plots can be moved by clicking the arrow buttons. You can replot the full plot at any time by selecting the "Spectrum/Temperature" pull-down menu item under the plots. Clicking the cursor on a plot will magnify the plot surrounding the location you clicked on (this is the technique you will use to isolate the lines you will be analyzing).

Besides information being printed in the text box at the upper left, this data is also stored in an ASCII file by the name runname.anal, where "runname" is the name of the run you are currently working on. You can print this file at any time by clicking on the "Print Output" button. When you do this on a Unix machine, the file will be printed automatically. If running in Microsoft Windows, a message box will come up giving you instructions on what you need to do to print this file.

When you are though with your analysis, click on the "Quit" button and then exit IDL. Finally, log off the account you are currently logged into.

5 The Data Analysis

You are to analyze the following set of lines for each of the runs with atanalyze.pro:

Line ID	**Air Wavelength**	**Vacuum Wavelength**
Ca I (2)	4226.728 Å	4227.918 Å
Mg I b1	5183.604 Å	5185.048 Å
Hα	6562.817 Å	6564.630 Å
Ca II ir3	8498.023 Å	8500.358 Å
Ca II ir2	8542.091 Å	8544.438 Å
Ca II ir1	8662.141 Å	8664.520 Å

The atanalyze IDL procedure will try to fit Gaussian profiles to the lines listed above. Once a line is fit, you will be asked if the fit is good enough for the analysis. If you select 'yes,' the formation depth of the line center and of the continuum under the line are marked on the temperature plot with a "*" and a "C", respectively.

In addition, you will need to access these line in the opacity (.opc) files. Each of the ATLAS runs were carried out in vacuum wavenumbers (cm^{-1}) at every integer Ångstrom from 10,000 Å to 3000 Å. As such, the opacity data files will contain those wavelengths that come closest to the vacuum wavelengths of the line centers. You will also have to retrieve data from the opacity files of the continuum that lies near a given line. Such points will be obvious in the .opc files since there will be no line opacity at those wavelengths.

You are to write a 5 to 10 page paper (not including title page, figures, or references), single-sided, doubled-spaced, concerning the analysis of your data. Key points that your paper should address in your analysis are:

1. What is the effect of stellar effective temperature on the strength of these lines? Why?
2. What is the effect of stellar surface gravity (for the same effective temperature) on the strength of these lines? Why?
3. What is the effect of metalicity (for the same effective temperature and surface gravity) on the strength of these lines? Why?
4. What spectral and luminosity classes best fits the stellar models with solar metalicities? How did you ascertain this?
5. What happens to $\lambda_{\rm max}$ as the metalicity is reduced for a given set of $T_{\rm eff}$ and $\log g$ models? Since the atmospheric structure is the same for each abundance run for a given effective temperature and surface gravity, how might you explain this shift?
6. The Ca II IR lines have a strange shape in the 7000 K models that is not apparent in the 4000 K models. Why is this?
7. Comment on the strength of the hydrogen Balmer lines between the 7000 K and the 4000 K main sequence models. As well, comment as to why the Balmer lines get stronger as metalicity is reduced for a given effective temperature and surface gravity.
8. Comment on the validity of fitting these lines with a Gaussian profile.
9. What are the strongest continuum opacity sources at the continuum formation depth under each of the lines listed above? Does the source(s) change with metalicity? Does the formation depth change with metalicity?

There are other things you can address in your report, I'll leave it to you to be creative. Various information that you need to address the above questions can be determined from the .out (*i.e.*, long output) and .opc (*i.e.*, opacity output) files. Don't wait until the last minute to do this project since it's going to take you a little time to get the hang of using the atanalyze package. Some of the questions raised above can be answered by plotting the

FWHM, equivalent width, or the integrated flux of the lines as a function of temperature, surface gravity, and/or metalicity (you'll have to figure out how to plot these yourself).

Finally, I recommend that you use LaTeX to write your papers. This manual has been written in LaTeX and I have included a LaTeX template file call a3415rep.tex that you can use to write your report. In this template file, an example is given to include an encapsulated postscript file for both LaTeX Unix and PCTeX on the Microsoft machines. On the PCs, just double click on the PCTeX icon to start LaTeX. Everything is controlled with GUI widgets in the PCTeX package. In Unix, issue the Unix command:

```
latex a3415rep
```

Assuming you have made no LaTeX programming errors, a *device-independent* file should have been created from this command called a3415rep.dvi. You next need to convert this file into a file that a printer can recognize. Since the Ultra 5 workstation in BH 260 is connected to the postscript printers in BH 264, issue the following command to make a postscript file:

```
dvips a3415rep
```

The result of this command will make a file called a3415rep.ps which you can then print out on the postscript printer with the Unix command:

```
lpr a3415rep.ps
```

Good luck and come in for help any time you need it.