CHIANTI

An Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas

USER GUIDE – Version 5.0 – 4 August 2005

Written by Giulio Del Zanna
with contributions from Peter Young and the team members.

Contents

1 What's new in Version 5.0

- Inclusion of ionization and recombination effects in level population calculation
- Photoexcitation from any user-provided radiation field
- Non-maxwellian distribution of electron velocities
- New data for
  - Fe IX, Fe X, Fe XII, Fe XV (EUV)
  - Fe XVII to Fe XXIV (X-rays)
  - n=3 to n=3 transitions for N-like and O-like ions
  - new ions (P XIV, XV; Cl II, X, XI, XII, XVII; K V, XVII, XIX; Ca VII, VIII; Co XX; Zn XXIII)
- The software has been improved and speeded. Fixed various minor bugs.
- A few new useful routines, in particular:

  `which_line`

  `pop_processes`

- Added keV option to calculate/plot spectra in energy units.

The changes introduced to speed the calculations were made necessary by the increasingly larger atomic models now available in CHIANTI, that made the running time of the software of the previous version too long.
The software is backward-compatible, i.e. can be used together with previous versions of the database.

2 Introduction

This document is mainly intended as a quick reference to some of the main features of CHIANTI.
Please read the CHIANTI USER GUIDE for more details.
CHIANTI is a collaborative project involving researchers based at the Naval Research Laboratory (NRL, Washington DC, USA), Rutherford Appleton Laboratory (RAL, UK), the University College London (UCL, UK), the University of Cambridge (UK), the George Mason Univerity (GMU, USA) and the University of Florence (Italy).
The CHIANTI package consists of a critically evaluated set of atomic data, a number of ancillary data and a suite of Interactive Data Language (IDL) programs.
The CHIANTI package is freely available. We only ask you to acknowledge and reference CHIANTI appropriately. See one of the CHIANTI WWW pages for details, e.g.:

- RAL, UK: `http://www.chianti.rl.ac.uk/`
- NRL, USA: `http://wwwsolar.nrl.navy.mil/chianti.html`

If a detail work on a particular ion is done, it would be appropriate to also refer to the original publication. References can be found at the end of each data file or on the WWW.
To keep updated on CHIANTI developments, please

- Read the CHIANTI pages on the WWW.
- Join the CHIANTI e-mailing list

We also have an e-mail address for questions: `chianti_help@halcyon.nrl.navy.mil`

3 The CHIANTI distribution and installation

CHIANTI is currently distributed in two ways.

3.1 Within SolarSoft

The main CHIANTI distribution is within SolarSoft, a programming and data analysis environment for the solar physics community. See `http://www.lmsal.com/solarsoft/` for details on how to download and install the package.
The database and the software are organised in a self-contained package

```
$SSW/packages/chianti/
```

with the following tree structure:

```
dbase/    (database)
doc/      (documentation, in particular the USER GUIDE)
idl/      (IDL software)
setup/    (supplementary setup files)
```

The contents of the SolarSoft CHIANTI package are mirrored daily from a master tree. Normally, only small fixes to the existing software can occur rather frequently.

All modifications to the software are logged in the `$SSW/packages/chianti/idl/HISTORY` file.
Modifications to the database are much less frequent. They are described in the `$SSW/packages/chianti/dbase/README_CHIANTI` file.
We send an e-mail to the CHIANTI user group every time we make a minor release of the database available.
We recommend that you use CHIANTI within the SolarSoft framework and that you setup in your site a mirror in order to have automatic upgrades.
Once the SSW package is installed, to run the CHIANTI routines all you need to do is

```
unix> setssw chianti
unix> sswidl
```

or to add the CHIANTI package once in SSW:

```
unix> sswidl
sswidl> ssw_packages,/chianti
```

3.2 As a stand-alone

CHIANTI is also distributed on the WWW, as tar files, via one the CHIANTI WWW pages. The tar files have a similar tree structure as the SolarSoft distribution.
E.g. the data are in CHIANTI_5.0_data.tar that contains a copy of `$SSW/packages/chianti/dbase`. CHIANTI_5.0_pro.tar contains `doc/`, a copy of `$SSW/packages/chianti/doc/` and `idl/`, a copy of `$SSW/packages/chianti/idl/`, plus `idl/gen/`, a copy of a subset of the `$SSW/gen/` routines. This is because some routines of the `$SSW/gen/` directory are needed to run some of the CHIANTI programs.
CHIANTI is a package, in the sense that database and progams are to be used together. The current version of the database should be used with the current version of the programs.

Download the CHIANTI files

Download the CHIANTI data tar file (e.g. CHIANTI_5.0_data.tar.gz) and the CHIANTI IDL procedures tar file (e.g. CHIANTI_5.0_pro.tar.gz) and put the tar files into a directory (for example, /data1/chianti/dbase for the data and /data1/chianti/ for the software) and then do the following:

```
unix> gunzip [file_name].tar.gz
unix> tar xvf [file_name].tar
```

This will copy all the CHIANTI data files into /data1/chianti/dbase and create the /data1/chianti/idl and /data1/chianti/doc/ directories.

Define the IDL paths and the system variables

To run any CHIANTI IDL procedure, the following is needed:

- Access to the CHIANTI IDL routines. The IDL !PATH should contain the paths to the directories where the CHIANTI IDL procedures are.
- Currently, the following IDL system variables need to be defined:
  - `!xuvtop` the top directory for the atomic database
  - `!ioneq_file` the default ionization equilibrium file
  - `!abund_file` the default elemental abundance file

– `!BCOLOR` , `!ASPECT`

There are many ways of doing the above. We suggest the following. Place the following statements in your IDL_STARTUP file:
Unix users (assuming that the IDL procedures are in `/data1/chianti/idl` and the data files are in `/data1/chianti/dbase`):

```
 !PATH = '+/data1/chianti/idl:'+!PATH
 !PATH = EXPAND_PATH(!PATH)
 use_chianti, '/data1/chianti/dbase'
```

Windows users (assuming that the IDL procedures are in `C:\data1\chianti\idl` and the data files are in `C:\data1\chianti\dbase`):

```
!PATH = '+C:\data1\chianti\idl;'+!PATH
!PATH = EXPAND_PATH(!PATH)
use_chianti, 'C:\data1\chianti\dbase'
```

The '+' and the EXPAND_PATH are needed since the IDL routines are organised into subdirectories.
`use_chianti` also allows you to set your default abundance and ionization equilibria files with the `abund` and `ioneq` keywords.
If you do not have an IDL STARTUP file you can create it (say `~/.idl\_startup`), and add in your `.login` file (Unix):
`setenv IDL_STARTUP ~/.idl_startup`
(Note that the changes to the .login file mean that you should do a `source ~/.login` before running IDL).
After following the above steps, it will be possible to run the CHIANTI routines from any directory by simply starting IDL.
Alternatively, instead of using `use_chianti, '/data1/chianti/dbase'`, you have to make sure you have in your IDL STARTUP file something like this:

```
 !PATH = '+/data1/chianti/idl:'+!PATH
 !PATH = EXPAND_PATH(!PATH)
defsysv,'!xuvtop', '/data1/chianti/dbase'
defsysv,'!ioneq_file', !xuvtop+'/ioneq/mazzotta_etal.ioneq'
defsysv,'!abund_file',!xuvtop+'/abundance/cosmic.abund'
defsysv,'!BCOLOR',0
defsysv,'!ASPECT',1.0
```

4 The database

The database has a tree structure, with the top directory designated with the IDL system variable `!xuvtop` (and named `dbase` within SolarSoft):

```
dbase/

In the top directory are the following files:

        README_CHIANTI    with the description of the current version.
        VERSION           with the version number.

Then, there is a series of subdirectories, one for each element present in the database.
Each element has  a subdirectory  for each ion.
The filename prefix for each ion follows spectroscopic notation.
For example, for He, we have He I and He II subdirectories:

        he/
           he_1/
           he_2/

Then, we have a series of ancillary data that are contained in
various subdirectories:

        masterlist/
                          has the list of the ions currently present
                          in the database
        abundance/        with elemental abundance files.
        continuum/        contains files for the continuum calculations.
        dem/              has DEM files.
        ioneq/            contains ionization fraction files.
        ip/               has ionization potentials.
        ancillary_data/instrument_responses/     with effective areas.
```

5 The Software

CHIANTI has been run mainly on Sun, Dec Unix workstations and on PCs with Linux. CHIANTI also runs (with some small limitations) under Windows NT and in VMS. Please report to us any problems you might find.
All the IDL routines have been documented with extensive headers giving detailed descriptions and examples. Please read them carefully. For example with:

```
IDL > xdoc,'ch_synthetic'
IDL > doc_library,'ch_synthetic'
```

The CHIANTI routines are organised in a tree structure. The main level contains some high-level procedures and the **HISTORY file, where all modifications to the software are logged**.
The high-level routines can be separated in two classes:

1. Routines called from the command line. These routines usually output arrays or structures, and optionally produce plots, postscript output or ascii files. Most of them have a long list of options, commanded via KEYWORDS. Please read the headers. Calling these routines without an argument will return a brief reminder of how to call the procedure.
2. Widget-type routines. These routines are more user-friendly, and are complementary of the above class.

6 Some examples on how to use the software

6.1 Calculating line intensities.

For an user-friendly, widget-based approach the best option is to use CH_SS:

```
IDL >ch_ss
```

This widget allows the user to calculate synthetic spectra in two basic steps. Basically, you follow the various widgets from top left to lower right to set the desired parameters. First calculate the line intensities. These values can be saved for later use. Next, specify further parameters such as the elemental abundances and instrumental spectral resolution and then calculate and plot the spectrum. These values can also be saved for later use. The HELP buttons in the widget provide short descriptions of the required information. See the USER GUIDE for more details.
Alternatively, for e.g. **background jobs**, the routine CH_SYNTHETIC can be used. `ch_synthetic.pro` calculates line intensities assuming constant pressure or density (or a model Te,Ne), **without the abundance factor**.
Example:

```
IDL> ch_synthetic, 10,20., output=str , pressure=1.e+15,$
       /photons, /noprot, /all, sngl_ion=['fe_17','fe_18'],$
    ioneq_name=concat_dir(concat_dir(!xuvtop,'ioneq'),'mazzotta_etal.ioneq'),$
       dem_name=concat_dir(concat_dir(!xuvtop,'dem'),'flare.dem'),$
```

This will calculate the **CHIANTI line intensities** between 10 and 20 Å for only Fe XVII and Fe XVIII and store them in the IDL structure `output`. Line intensities are calculated at constant pressure of 10^{15}, have units of photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$ (KEYWORD photons), the proton rates are not included (KEYWORD noprot), and all the lines (KEYWORD all) are included (also the lines with only theoretical energy levels). The program will prompt the user to select an ionization balance and an emission measure file, if these parameters are not supplied via the keywords `ioneq_name= , dem_name=`.
You can see the contents of the structure with e.g.

```
IDL> help, str,/st
IDL> help, str.lines[0],/st
```

Table 1: List of main-level routines

Synthetic spectra	
`ch_ss`	Multi-purpose widget to calculate line intensities, create synthetic spectra adding the continuum, tables and various outputs.
`synthetic`	Calculates a synthetic spectrum. Outputs arrays.
`synthetic_plot`	Plots the spectrum created by synthetic.pro and interactively identify lines
`isothermal`	Calculates a synthetic spectrum with an isothermal approximation. Outputs arrays.
`make_chianti_spec`	Creates a synthetic spectrum. Works with structures.
Line intensities	
`ascii_wvl_dem`	Creates an ascii file with a list of line identifications and intensities.
`latex_wvl_dem`	Creates a latex file with a list of line identifications and intensities.
`ch_synthetic`	Multi-purpose routine that calculates line intensities (without any abundance factor), and outputs an IDL structure.
`ch_line_list`	Multi-purpose routine that creates ascii and latex files with lists of line identifications and intensities. Takes as input the structure created by CH_SYNTHETIC.
Line emissivities	
`emiss_calc`	To compute the emissivities of all lines of a specified ion over given ranges of temperature and density.
`gofnt`	Calculates the contribution functions G(T)
`g_of_t`	To compute the G(T) of selected lines.
Density-sensitive line ratios	
`dens_plotter`	A widget routine to allow the analysis of density sensitive ratios.
`density_ratios`	Plots the variation of line intensities with electron density
`chianti_ne`	A widget to calculate and plot density sensitive line ratios.
`plot_chianti_ne`	Plots density sensitive ratios saved from CHIANTI_NE
Temperature-sensitive line ratios	
`temp_plotter`	A widget routine to allow the analysis of temperature sensitive ratios.
`temperature_ratios`	Plots the variation of line intensities with electron temperature .
`chianti_te`	A widget to calculate and plot temperature sensitive line ratios.
`plot_chianti_te`	Plots temperature sensitive ratios saved from CHIANTI_TE
Continuum	
`freefree`	calculates the free-free (bremsstrahlung) continuum.
`freebound`	calculates the free-bound continuum.
`two_photon`	calculates the two-photon continuum.
Level populations	
`show_pops`	To display populations of significant levels in a CHIANTI ion model.
`plot_populations`	plots the level populations
`pop_plot`	To plot $n_j A_j i/N_e$ values as a function of N_e.
`pop_processes`	Outputs to the screen the contributions of the different physical processes to the population of the specified level within an ion.
Miscellaneous	
`rad_loss`	Calculates the radiative losses
`max_temp`	Calculates temperature at max ionisation ratio for an ion.
`plot_ioneq`	Plots the ionisation equilibrium values for an element.
`chianti_dem`	Calculates the Differential Emission Measure DEM(T) using the CHIANTI database, from a given set of observed lines.
`plot_dem`	To plot differential emission measure (DEM) values
`integral_calc`	To compute the atomic data integral for use in column or volume emission measure work.
`ch_read_fits`	Read standard CHIANTI FITS binary table data containing the output from CH_SYNTHETIC and outputs a CHIANTI line intensities structure.
`ch_write_fits`	Write standard FITS binary table data from CHIANTI line intensities structure.

The last command shows the first structure associated with the first spectral line.
The CHIANTI line intensities structure can be saved and later restored from the command line in various ways. We suggest two:

1. as IDL binary files using the SolarSoft routines:

   ```
   IDL> savegen, file='ch_int_10_20_fe.genx', struct=str
   IDL> restgen, file='ch_int_10_20_fe.genx', struct=str
   ```

   to save and restore the IDL structure `str` in the file `ch_int_10_20_fe.genx`.

2. as FITS binary tables, that can be easily exported and read by different platforms. We have written two IDL routines:

   ```
   IDL> ch_write_fits, str, 'output.fits'
   IDL> ch_read_fits,'output.fits', str
   ```

   to save and restore the IDL structure `str` in the FITS file `output.fits`.

In either case, the structure saved in the `.genx` and `.fits` files can be restored via the widget CH_SS to later create a spectrum or tables of line intensities. Alternatively, you can use CH_LINE_LIST to multiply for the abundance factor and output tables of line intensities. For example:

```
IDL> restgen, file='ch_int_10_20_fe.genx', struct=str
IDL> ch_line_list, str, 'ch_line_list.tex', /latex,$
     abundfile=concat_dir(concat_dir(!xuvtop,'abundance'),'cosmic.abund'),$
     mini=1e13
```

This creates a latex file `ch_line_list.tex` where only lines with an intensity greater than 10^{13} (KEYWORD mini) are included, and the `allen.abund` file in the standard CHIANTI distribution is used (if not supplied it can be selected with a widget). Then, you have to latex the file three times, and optionally `xdvi` it:

```
unix> latex ch_line_list
unix> latex ch_line_list
unix> latex ch_line_list
unix> xdvi ch_line_list
```

If you do not have it already, you will need the package longtable.sty that is distributed as part of `ftp://cam.ctan.org/tex-archive/macros/latex/required/tools.tar.gz`
You will obtain a table that looks like:

Table 2: *Line List*

Ion	λ (Å)	Transition	T_{max}	Int
Fe XVII	12.1227	$2p^6\ ^1S_0$ - $2p^5\ 4d\ ^1P_1$	6.9	1.11e+14
Fe XVII	12.2639	$2p^6\ ^1S_0$ - $2p^5\ 4d\ ^3D_1$	6.9	9.81e+13
Fe XVII	13.8231	$2p^6\ ^1S_0$ - $2s\ 2p^6\ 3p\ ^1P_1$	6.9	6.25e+13
Fe XVIII	13.9540	$2s^2\ 2p^5\ ^2P_{3/2}$ - $2p^4\ (^1S)\ 3d\ ^2D_{5/2}$	6.9	2.06e+13
Fe XVIII	14.1519	$2s^2\ 2p^5\ ^2P_{3/2}$ - $2p^4\ (^1D)\ 3d\ ^2D_{3/2}$	6.9	1.35e+13

To **create an ascii file with the line details** you can follow a similar approach, i.e.:

```
IDL> restgen, file='ch_int_10_20_fe.genx', struct=str
IDL> ch_line_list, str, 'ch_line_list.ascii', /ascii,$
     mini=1e13
```

6.2 Calculating continuum intensities

For example, to calculate the free-free, free-bound and two-photon continuum at a temperature of 5×10^6 K, for wavelengths at 1 Å intervals between 1 and 50 Å:

```
freefree,5.e+6,findgen(50)+1.,ff
freebound,5.e+6,findgen(50)+1.,fb
two_photon,5.e+6,findgen(50)+1.,tp

window,0
plot,findgen(50)+1.,ff+fb+tp,xtit='Wavelength (A)'
oplot, findgen(50)+1.,ff,line=2
oplot, findgen(50)+1.,fb,line=3
oplot, findgen(50)+1.,tp,line=4
```

Note that the intensities are in units of 10^{-40} ergs cm^3 s^{-1} sr^{-1} Å^{-1} per unit emission measure $\int N_{\mathrm{H}} N_{\mathrm{e}} dh$ (cm^{-5}).
If DEM values are passed to the routines (via the keyword DEM_INT), it is assumed that they are given as $N_{\mathrm{H}} N_{\mathrm{e}} dh/dT$. The units are 10^{-40} ergs cm^{-2} s^{-1} sr^{-1} Å^{-1} in this case.

6.3 Creating a synthetic spectrum with the continuum

The structure created by CH_SYNTHETIC can be restored via CH_SS to create a spectrum. Alternatively, it can be used as an input to the program MAKE_CHIANTI_SPEC. This program creates the **CHIANTI SPECTRUM structure**, an OUTPUT structure similar to the structure created by CH_SYNTHETIC, with some additional tags. Following the previous example:

```
IDL> restgen, file='ch_int_10_20_fe.genx', struct=str
IDL> make_chianti_spec, struct, lambda, struct, /CONTINUUM,$
     BIN_SIZE=0.01, instr_fwhm=0.1,  WRANGE=[10.,19.],$
```

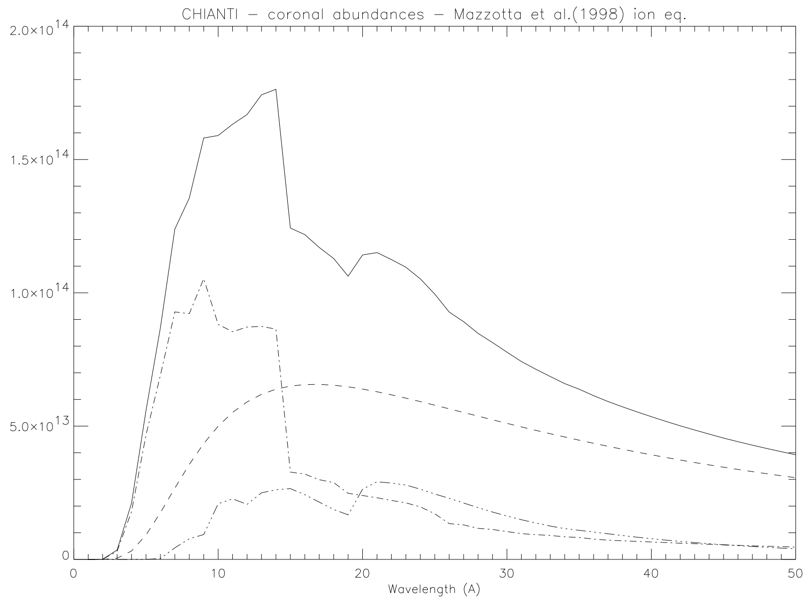

Figure 1: Continuum in the 1-50 Å range.

```
abund_name=concat_dir(concat_dir(!xuvtop,'abundance'),'cosmic.abund')
```

To see the contents of the structure:

```
IDL> help, struct,/st
IDL> help, struct.lines[0],/st
```

While to show the spectrum and the main contributing lines:

```
IDL> window,0
IDL> plot,struct.lambda,struct.spectrum,psym=10,xr=[11,18],/xst,$
IDL> xtit='Wavelength (A)',ytit='photons cm-2 sr-1 s-1 A-1'
IDL>    for i=0,n_elements(struct.lines) -1 do begin
IDL>      if struct.lines[i].peak gt 7e5 then begin
IDL>        xyouts, struct.lines[i].wvl,  struct.lines[i].peak, struct.lines[i].snote
IDL>        oplot,[struct.lines[i].wvl,struct.lines[i].wvl],[0,struct.lines[i].peak]
IDL>      end
IDL>    end
```

It may be useful to save the SPECTRUM structure, that can be later inspected with the widget CH_SS:

```
IDL> savegen, file='ch_spectrum_10_20_fe.genx', struct=struct
IDL> ch_write_fits, struct, 'ch_spectrum_10_20_fe.fits'
```

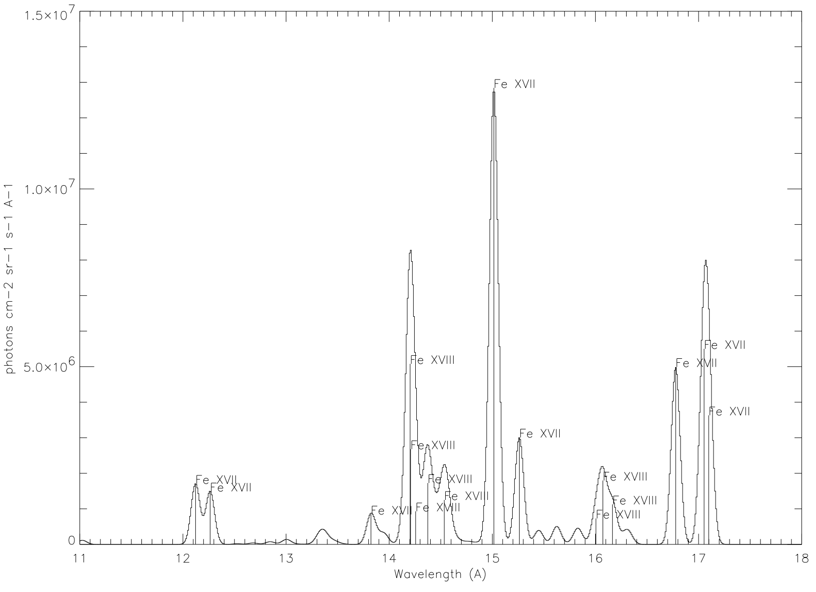

Figure 2: Synthetic spectrum created by MAKE_CHIANTI_SPEC.

6.4 Density and temperature diagnostics from line ratios

DENS_PLOTTER and TEMP_PLOTTER are high-level widgets for the analysis of density- and temperature-sensitive ratios of lines from the same ion. They allow inclusion of proton rates and photoexcitation. The calling sequence is simple:

```
IDL > dens_plotter,'o_5'
```

to study O V.

```
IDL > temp_plotter,'c_4'
```

to study C IV.
Alternatively, you can use the command-line routines, DENSITY_RATIOS and TEMPERATURE_RATIOS. They also allow inclusion of proton rates and photoexcitation via KEYWORDS.

The DENSITY_RATIOS procedure

The routine DENSITY_RATIOS plots the variation of line intensities with electron density, allowing density diagnostics to be studied. As an example, we can look for density sensitive line ratios of O V in the 1000 to 1500 Å wavelength region for densities between 10^8 and 10^{13} cm^{-3}:

```
IDL >density_ratios,'o_5',1000.,1500.,8.,13.,den,rat,desc
```

two windows will open and plot the relative intensities of a few O V lines. To choose the ratio of 1371.294 to 1218.393 Å line, select first the 1371.294 Å line. Another widget will

appear to select the denominator. Select the 1218.393 Å line. This will chose the ratio of 1371.294 to 1218.393 which will be plotted in a new window. Values of the density and intensity ratio will be put into the variables den and rat and desc will contain a descriptive string. By specifying the keywords outfile and psfile, the ratios values and plots will be saved in files.
The DENSITY_RATIOS procedure also allows to calculate the ratio at user-defined value of constant temperature. Blends are accounted for via a selection of lines.

The TEMPERATURE_RATIOS procedure

To calculate temperature sensitive line ratios of C IV for lines between 100 and 1600 Å for temperatures between 10^4 and 10^6 K:

```
IDL >   temperature_ratios,'c_4',100.,1600.,4.,6.,temp,rat,desc
```

As with density_ratios, a widget will appear that will allow you to select the numerator. Select the 384.175 and 384.190 Å lines as these will typically be blended in most spectrographs. Select the 1550.775 Å line for the denominator. The ratio of (384.175 + 384.190 Å) to the 1550.775 Å line as a function of temperature will be plotted and stored in the variables rat and temp, respectively. The TEMPERATURE_RATIOS procedure also allows to calculate the ratio at user-defined values of either constant pressure or constant density. As with `density_ratios`, the outfile and psfile keywords specify output files.

6.5 Looking at level populations

To plot the populations of the first 4 levels of Si III as a function of density at a temperature of 3 x 10^4 K:

```
IDL > plot_populations,'si_3',3.e+4,4
```

Optionally, output files can be created.

6.6 Looking at the different ionisation equilibria

If you are interested to see the differences between the various ionisation equilibria for e.g. Mg, you can use:

```
IDL > plot_ioneq,'Mg'
```

You will be able to select one of the files, and optionally create a postscript file of the plot.

6.7 Calculating contribution functions

To calculate the contribution function ($erg\ cm^3 s^{-1} sr^{-1}$ by default) vs. temperature at a specified abundance, ionization equilibrium and pressure or density for the Fe XXIV line at 255.1 Å:

```
IDL >  gofnt,'fe_10',170.,180.,temperature,g,desc
```

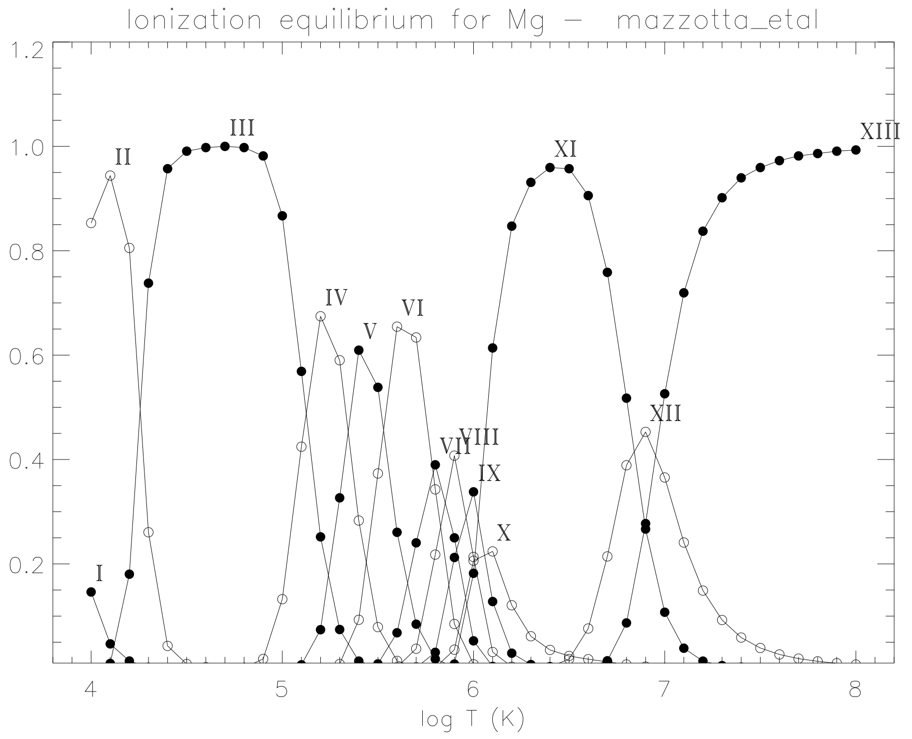

Figure 3: Output plot of PLOT_IONEQ

temperature, g are the arrays with the temperatures and the G(T) values. It is possible to calculate the G(T) at either constant electron density or pressure, via the KEYWORDS DENSITY or PRESSURE. The routine GOFNT allows the user to select a number of lines. If this is done, then the total sum of the G(T)'s of the selected lines is returned and plotted. The KEYWORDS ABUND_NAME, IONEQ_NAME allow to run the routine in the background, giving names of the abundance and ionization fractions files.

6.8 Calculating radiative losses

A procedure ('RAD_LOSS') calculates the total radiative loss rate as a function of temperature for specified set of abundances and/or ionization equilibria:

```
IDL > rad_loss,temperature,loss_rate
```

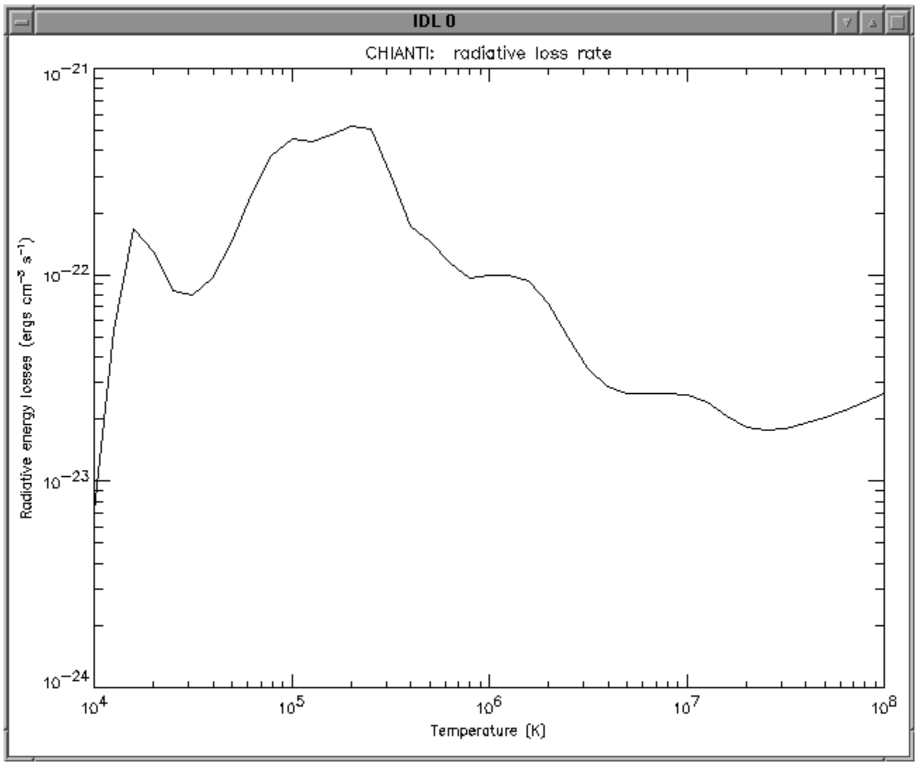

Figure 4: Output plot of RAD_LOSS