

CHIANTI

An Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas

USER GUIDE – Version 6.0 – 10 July 2009

Written by Giulio Del Zanna & the CHIANTI team.

Contents

1	What's new in Version 6.0	2
2	Introduction	3
3	The CHIANTI distribution and installation	3
3.1	Within SolarSoft	4
3.2	As a stand-alone	4
4	The database	6
5	The Software	7
6	Some examples on how to use the software	7
6.1	Calculating line intensities.	7
6.2	Calculating continuum intensities	10
6.3	Creating a synthetic spectrum with the continuum	11
6.4	Density and temperature diagnostics from line ratios	13
6.5	Looking at level populations	14
6.6	Looking at the different ionisation equilibria	14
6.7	Calculating contribution functions	14
6.8	Calculating radiative losses	15
6.9	V.6 additional routines	15

1 What's new in Version 6.0

CHIANTI 6 includes a complete database of ionization and recombination coefficients for the first 30 elements of the periodic table, as well as a new ionization equilibrium. We also provide IDL programs to read the rates.

Major features (Dere et al. 2009, A&A, 498, 915) in CHIANTI 6 are:

- inclusion of ionization and recombination rates
- new ionization equilibrium calculation
- improved calculation of He-like line intensities (X-rays)
- new data for Be-like and F-like sequences (EUV)
- new data for Fe XVII to Fe XXIII (X-rays)
- new data for n=3 to n=3 N-like and O-like transitions (UV)
- some additional IDL programs:

Table 1: List of routines added in Version 6.0

Ionization and recombination rates	
<code>ioniz_cross</code>	Returns the cross section for electron collisional ionization
<code>ioniz_rate</code>	returns the ionization rate coefficient
<code>recomb_rate</code>	returns the recombination rate coefficient
<code>make_ioneq_all</code>	Calculates ion fractions in ionization equilibrium
Various utilities	
<code>level_lifetime</code>	Calculates the lifetime of a level using the radiative decay rates stored in the CHIANTI .wgfa file.
<code>metastable_levels</code>	This routine returns a list of levels in an ion that are metastable.
<code>plot_config_energies</code>	This routine graphically displays the configuration energies for an ion.
<code>rate_coeff</code>	This routine allows you to extract electron rate coefficients, both for individual transitions and the complete array of transitions. The rate coefficient is returned in units $\text{cm}^3 \text{s}^{-1}$.
<code>spl2ups</code>	Converts the CHIANTI spline fits to upsilons (thermally-averaged collision strengths) for a specified ion, transition and temperature

The IDL programs have been redistributed within a new directory tree, as follows:

```
ionrec/    Routines to access and use ionization and recombination rates
synt_spec/ Routines to calculate line emissivities/intensities and synthetic spectra
emiss/     Routines to calculate line emissivities
continuum/ Various continuum routines
ratios/    Routines to plot line ratios
```

level_population/ Routines that deal with level populations
em/ EM routines
dem/ DEM routines
convert/ Miscellaneous conversion routines
utilities/ Miscellaneous utility routines
read/ Routines to read the various CHIANTI files
setup/ Setup routines

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), the George Mason University (GMU, USA), the University of Cambridge (UK), and the University of Florence (Italy). Rutherford Appleton Laboratory (RAL/STFC, UK) hosts the UK web pages.

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://chianti.nrl.navy.mil/>

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 CHIANTI5.0_data.tar that contains a copy of \$SSW/packages/chianti/dbase. CHIANTI5.0_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 programs 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_6.0_data.tar.gz) and the CHIANTI IDL procedures tar file (e.g. CHIANTI_6.0_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:
 - !xvtop 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/chianti.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, on Macs 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
```

Table 2: 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 CHSYNTHETIC.
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 CHSYNTHETIC and outputs a CHIANTI line intensities structure.

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 $\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ (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
```

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 3: *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

```

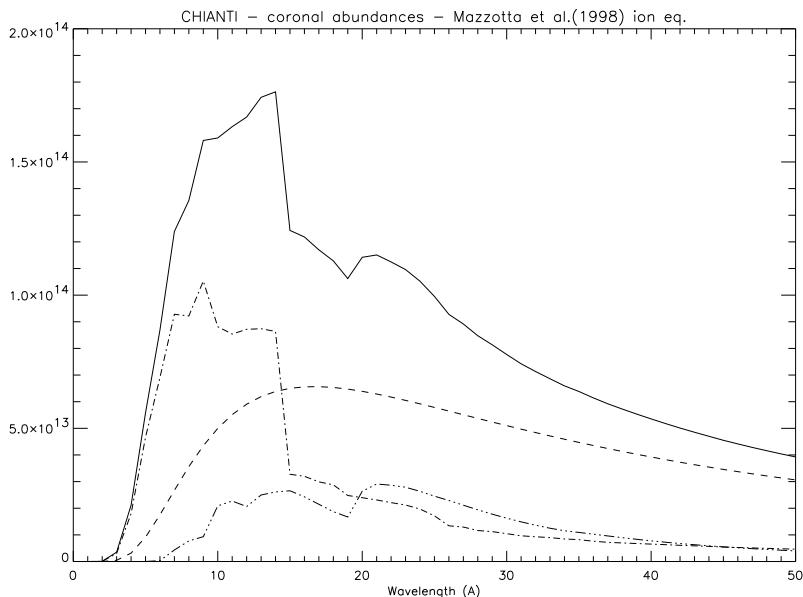


Figure 1: Continuum in the 1-50 Å range.

Note that the intensities are in units of 10^{-40} ergs $\text{cm}^3 \text{s}^{-1} \text{sr}^{-1} \text{Å}^{-1}$ per unit emission measure $\int N_{\text{H}}N_{\text{e}}dh$ (cm^{-5}).

If DEM values are passed to the routines (via the keyword `DEM_INT`), it is assumed that they are given as $N_{\text{H}}N_{\text{e}}dh/dT$. The units are 10^{-40} ergs $\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{Å}^{-1}$ 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.],$

```

```
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
```

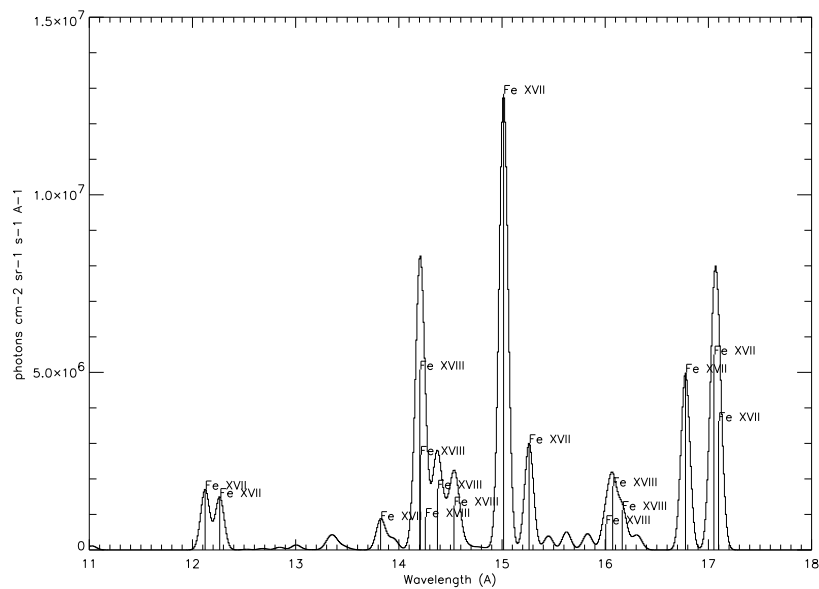


Figure 2: Synthetic spectrum created by MAKE_CHIANTI_SPEC.

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'
```

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 3×10^4 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.

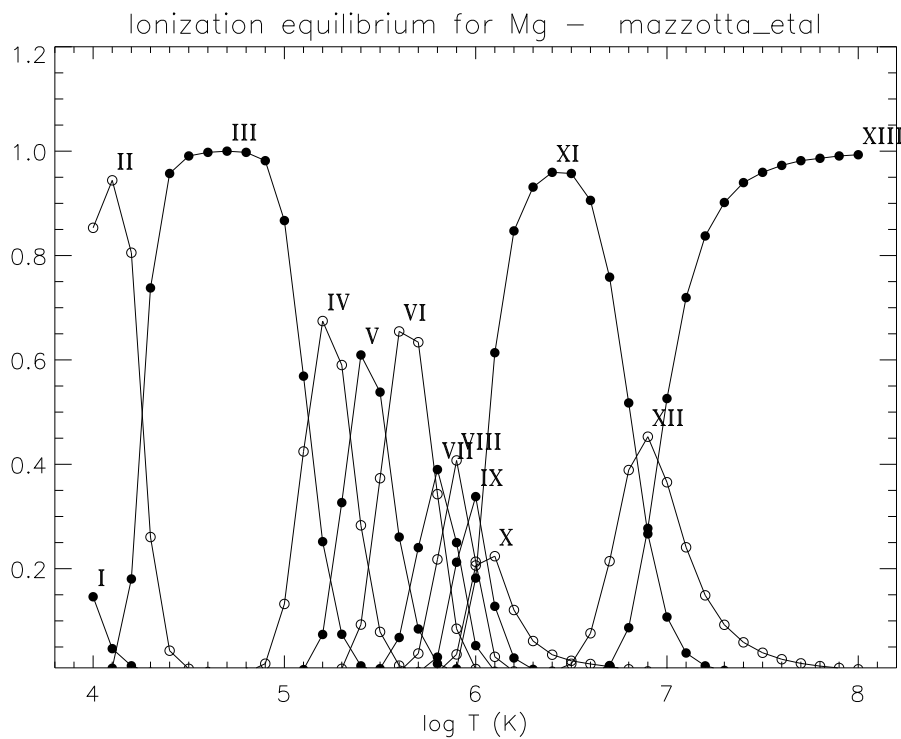


Figure 3: Output plot of PLOT_IONEQ

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 $255.1\ \text{\AA}$:

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

`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
```

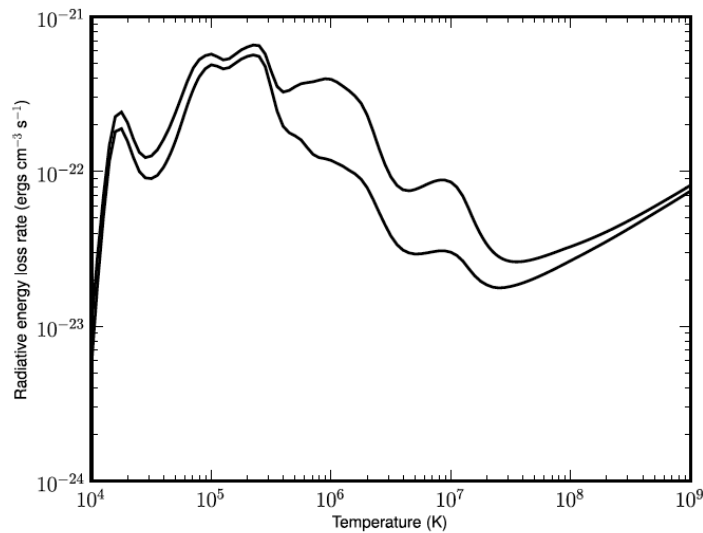


Figure 4: Radiative loss rate for coronal abundances (upper curve) and photospheric abundances (lower curve). From CHIANTI v.6, output plot of `RAD_LOSS`

6.9 V.6 additional routines

```
IDL> cross = ioniz_cross(ion,energy [, z=, ion= ])  
%$
```

`cross` is returned as the ionization cross section (cm^2) as a function of the specified ion and energy in (eV). The process of direct ionization and excitation-autoionization are both included. For example,

```
cross = ioniz_cross('h_1',[14.,20.]
```

returns the cross section for electron collisional ionization of H I to H II. Note that if the energies are below the ionization potential, 13.6 eV for H I, then a cross section of zero is returned for those energies.

```
IDL> rate = ioniz_rate(ion, temperature [, z= , ion =])
```

rate is returned as the ionization rate coefficient ($\text{cm}^3 \text{s}^{-1}$) as a function of the specified ion and temperature (K). The processes of direct ionization and excitation-autoionization are both included. For example,

```
IDL> rate = ioniz_rate('fe_14',[1.e+6, 2.e+6])
or
IDL> rate = ioniz_rate('',[1.e+6, 2.e+6], z=26, ion=14)
```

returns the rate coefficient for the ionization of Fe XIV to Fe XV at 2 temperatures. The processes of radiative and dielectronic recombination are both included.

```
IDL> rate = recomb_rate(ion, temperature [,z=, ion=])
```

rate is returned as the recombination rate coefficient ($\text{cm}^3 \text{s}^{-1}$) as a function of the specified ion and temperature (K). For example,

```
IDL> rate = recomb_rate('fe_14',[1.e+6, 2.e+6])
```

returns the rate coefficient for the recombination of Fe XIV to Fe XIII at 2 temperatures. As an example, Fig 5 shows the ionization and recombination rate coefficients for Fe IX ('fe_9').

```
IDL> make_ioneq_all, temperature, outname='new.ioneq'
```

a file 'new.ioneq' is created in the users working directory containing the ionization equilibrium calculated at the specified temperatures for all elements from H through Zn. Users can specify a different file name but the .ioneq extension is generally expected by the CHIANTI software.

```
IDL> level_lifetime,'fe_13',4,lifetime
Level:      3s2.3p2 1S0
Lifetime (seconds):  9.098e-04
```

This routine calculates the lifetime of a level using the radiative decay rates stored in the CHIANTI .wgfa file. The 2nd input is the CHIANTI level index for the level you are interested in (see the CHIANTI .elvlc file). The level lifetime is returned in seconds.

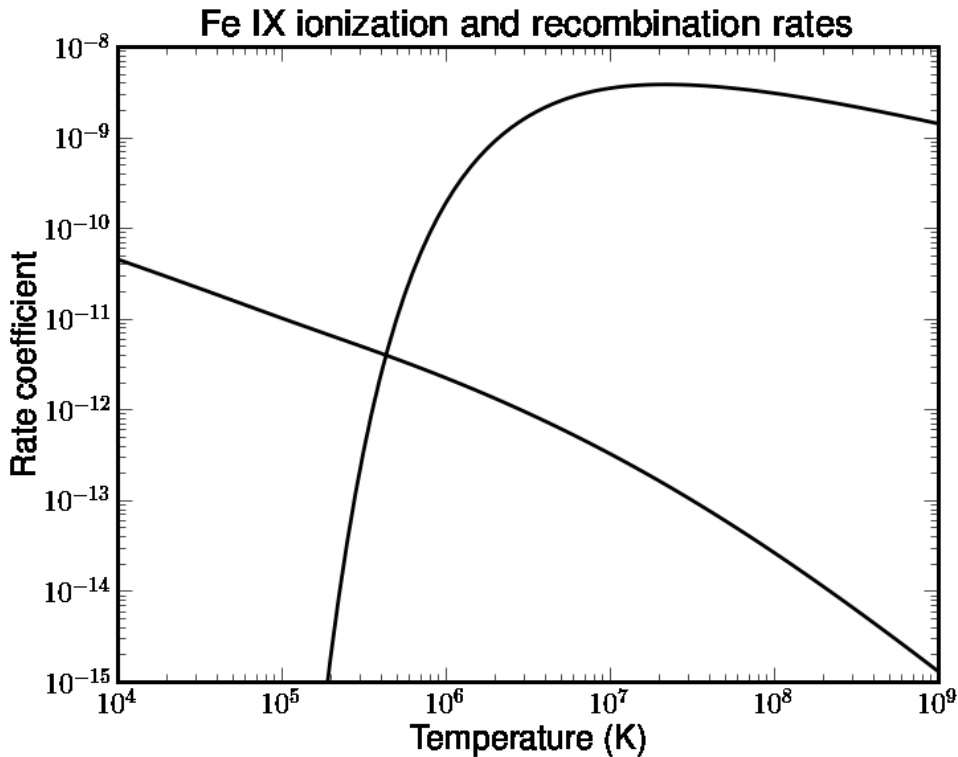


Figure 5: Ionization and recombination rate coefficients for Fe IX

```
IDL> metastable_levels, 'fe_13', meta
Metastable levels are:
 1 3s2.3p2 3P0
 2 3s2.3p2 3P1
 3 3s2.3p2 3P2
 4 3s2.3p2 1D2
 5 3s2.3p2 1S0
18 3s2.3p3d 3F4
```

This routine returns a list of levels in an ion that are metastable. 'meta' is an array with N elements, where N is the number of levels in the CHIANTI ion model. It contains values of either 0 or 1, where 1 denotes that the level is metastable.

Metastable levels are identified as those for which the largest radiative decay rate is $\geq 10^5$ s⁻¹. This value can be modified by specifying the keyword cutoff=

```
IDL> plot_config_energies, 'o_5'
```

This routine graphically displays the configuration energies for e.g. O V. For each configuration a box is drawn whose lower and upper edges represent the minimum and maximum energies, respectively, of the levels belonging to that configuration.

```
IDL> cc=rate_coeff('fe_13',1e6)
```

calculates the complete rate coefficient array for Fe XIII. The rate coefficient is returned in units $\text{cm}^3 \text{s}^{-1}$. There are 27 levels in the CHIANTI model for Fe XIII and so cc is an array of size 27 x 27. To calculate the rate coefficient for a particular transition, do:

```
IDL> cc=rate_coeff('fe_13',1e6,trans=[1,20])
```

```
Wavelength: 202.04
```

```
Exc. rate coeff: 7.307e-09
```

```
De-exc. rate coeff: 4.964e-09
```

Only the excitation rate coefficient is returned in cc. To return the de-excitation coefficient, set trans=[20,1].

```
IDL> ups=spl2ups('fe_13',[1,20],1e6)
```

The routine spl2ups converts the spline fits stored in CHIANTI to effective collision strengths (upsilons, as a function of temperature) for a specified ion, transition and temperature. In the example, 1-20 is the transition (check the .elvlc file for index notation), and 1e6 is the temperature in Kelvin.