CORONAL DIAGNOSTIC SPECTROMETER

SoHO

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The CHIANTI Synthetic Spectrum Program for CDS/SUMER

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1 Introduction

Plasma emission codes have long been used to study UV and X-ray spectral lines from the solar atmosphere. A comparison of the theoretical line intensities with the observed intensities allows a determination of the physical parameters for the plasma (cf Mason and Monsignori Fossi, 1994). If the theoretical intensities are processed using relevant instrument parameters, it also allows one to identify complications with the observational analyses, such as line blends. A comparison and critique of available plasma emission codes developed by different groups is presented in Brickhouse *et al* (1995) and Mason (1995). These codes require the input of a large amount of atomic data. Following Mewe (1972), most codes used a type of semi-classical ($\bar{g}$) approximation to represent the electron excitation rates. This type of parameterisation / approximation has severe limitations. It is very important, now that high accuracy atomic data are available, to improve the quality of the electron excitation rates in the plasma codes. Recent developments in the Arcetri plasma emission code are discussed in Monsignori Fossi and Landini (1994, 1995).

CHIANTI, developed by Dere, Landi, Mason, Monsignori Fossi and Young, aims to provide a straightforward, easy-to-use package comprising an atomic databank and accompanying IDL routines. Ions from elements which are cosmically abundant have been included. Theoretical line intensities (ie synthetic spectra) are calculated assuming equilibrium conditions and optically thin spectral line emission. The first release of the CHIANTI package was in July 1996. The atomic data and IDL routines are available by anonymous FTP from http://wwwsolar.nrl.navy.mil/chianti.html. An accompanying publication has been submitted to Astronomy and Astorphysics Suppl. Series.

Sadly, during the course of this work, our collaborator and collegue Brunella Monsignori-Fossi died suddenly and prematurely. Her enthusiasm, support and friendship is a great loss not only to us but to the whole SOHO community.

2 The atomic data

The best available atomic data have been used and the original sources are documented in each data file. We are particularly grateful to authors for making their atomic data available to us via FTP and E-MAIL. It is anticipated that the atomic data will continue to be updated regularly as new data are calculated or measured in the laboratory. It is intended that these atomic data can be accessed and transfered into users own analysis programs, for more sophisticated applications.

The atomic database consists of a directory for each element, with a subdirectory for each ion. The filename prefix for each ion follows spectroscopic notation ; eg FeXIV is fe_14. There are three primary ASCII files for each ion (energy levels - fe_14.elvlc; radiative data and wavelengths - fe_14.wgfa; electron excitation data - fe_14.splups)

The energy levels (.elvlc) have been obtained from NIST. Where necessary, these have been supplemented by other laboratory and theoretical values. The radiative data (.wgfa) have been taken from published literature and where necessary, supplemented by new calculations. The wavelengths given in the .wgfa files are the best available values and should accurately reproduce the observed spectra.

The electron excitation data have been assessed and fitted using the Burgess and Tully (1992) method. These authors developed an interactive graphical procedure (OMEUPS) to assess and fit electron collision strengths (Ω) and to obtain the effective collision strengths (Υ). The Ω's (or Υ's) are plotted on a reduced energy (or temperature) scale such that 0 corresponds to threshold (or zero temperature) and 1 corresponds to infinite energy (or temperature). The correct functional behaviour of the Ω's (or Υ) on energy (or temperature), which depends on the type of transition (i.e. dipole, exchange, forbidden), is taken into account. The high energy (or temperature) limit can also be obtained from the Bethe or Born approximations. A five-point spline is fitted to the reduced data by a least squares procedure. Published data from different sources are all stored in the same format, with only five points required to reproduce the whole energy (or temperature) range. Burgess and Tully's original program was written in BBC BASIC. A new version, called BURLY (BURgess and tulLY!), has been written in IDL by Ken Dere, for ease of use with solar analysis and other software. It is an interactive package which uses IDL widgets. This allows one to inspect and assess large quantities of collisional data at a reasonable pace. All the atomic data in the CHIANTI database have been visually displayed and assessed for accuracy and any sporadic errors which sometimes creep into published results. The starting point for the electron excitation rate data was the comprehensive bibliographies and compilations by Itikawa (1991), Pradhan and Gallagher (1992) and Lang (1994) but we also include more recent work.

3 The CHIANTI_SS procedure

The IDL procedure which calculates synthetic spectra based upon the CHIANTI data is called CHIANTI_SS. To run this procedure, access to the CDS IDL directories is needed and the environment variable $CDS_SS_DERE must be set up to point to the top atomic data data directory.

3.1 Selecting the wavelength range

In order to provide easy selection of the wavelength range, it is possible from the main window to select the instrument and (for CDS) the associated detector. This choice will automatically load the relevant wavelength range.

The wavelength sliders are provided to allow the user to fine tune the wavelength range over which the calculation is performed.

3.2 Selectable 'solar' parameters

3.2.1 Plasma Pressure

The spectra are based on calculations at a constant pressure, which is the simplest assumption for the solar atmosphere. The units used are (NeTe cm^{-3}).

3.2.2 Emission measure

The emission measure distribution in the solar atmosphere is a topic of hot debate. Starting with the pioneering work by Pottasch (1964), spectra in the UV wavelength range have been used to determine the distribution of material as a function of temperature. Recent work includes that on the active region spectrum from the SERTS-89 rocket flight (Monsignori Fossi *et al*, 1994). A comparison of different inversion techniques to solve the differential emission measure problem is given in Harrison and Thompson (1992). Here, we provide "standard" emission measure distributions for different solar features (coronal hole, quiet Sun, active region) (Dere and Mason, 1993). User defined files containing DEM information can be included in the current working directory and, provided they have the .dem extension will automatically be appended to the list of available DEMs.

Once a selection of DEM is made, the DEM values are plotted.

3.2.3 Elemental abundances

There is a great deal of controversy over the variation (or not!) of elemental abundances in the upper solar atmosphere. Various methods have been used to determine the elemental abundances in the transition region and corona. Reviews on this subject include Meyer (1985, 1993), Widing and Feldman (1992), Mason (1992). Indeed a recent COSPAR meeting was devoted to this topic and the papers are published in Bely-Dubau (1995). Options are available to choose different elemental abundances. (Allen, 1973, Grevesse *et al*, 1991, Meyer, 1985, Waljeski *et al*, 1994). User defined abundance files can be made available as described above for DEM files except the file extension must be .abund.

When a particular abundance is selected, the abundance values to be used are listed in the message window.

3.2.4 Ionisation ratios

The ionisation ratios have been taken from the published literature. There are large discrepancies for the iron ions between Arnaud & Raymond (1992) and Arnaud & Rothenflug (1985). Shifts on the order of 0.1-0.2 dex are found in the temperatures corresponding to peak ion abundances. The peak values of the ionisation ratio typically differ by 10-20%. These differences warrant further investigation. Detailed studies of the formulations used to calculate ionisation and recombination rates can be found in the recent paper by Jordan (1995). The main questions to be addressed are the more accurate account of indirect processes in the ionisation rates and the treatment of electron density dependence and alternative decay channels in the di-electronic recombination rates. Options are provided to select different ionisation equilibrium calculations. User defined ionisation files can be made available as described above for DEM files except the file extension must be .ioneq.

3.3 Controlling the procedure

The action of CHIANTI_SS is controlled via the buttons in the central panel of the display. From left to right these are:

QUIT - click on this to exit from the program

CALCULATE SPECTRUM - using the setup as defined in the widgets, calculate a new synthetic spectrum.

LINEAR INTENSITY PLOT - this is a toggle button which will toggle between linear and logarithmic plotting on the spectrum's intensity scale.

HARDCOPY - the menu under this button will allow a variety of hardcopy plots and listings. The spectrum plot plus setup details is meant to give a concise record of the input and result.

SAVE - since the calculation of the spectrum can take several minutes, it is useful sometimes to save the spectrum for later use. The program saves the line list (and associated data) in an ascii file, named by the user. This file can be read outside of CHIANTI_SS using the function RD_CHIANTI. All files are given the suffix .CH for easy identification.

RESTORE - this button gives the user a choice of saved files to restore. The chosen one is automatically loaded onto the screen display.

REPLOT - if the wavelength range selection or plot scaling is changed, press this button to get the data replotted within those limits.

BROADENED - hit this button if you wish the instrumentally broadened spectrum to be plotted. The synthetic spectra are convolved with the default spectrograph psf.

RAW - this will ensure that the raw (unbroadened) synthetic spectrum is displayed.

BOTH - both the raw spectrum and the instrumentally broadened version are displayed. This is useful to see what lines are contributing to a profile.

Clicking the cursor on any part of the displayed spectrum will give a listing of the lines within 0.5 Angtroms of that wavelength.

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