CORONAL DIAGNOSTIC SPECTROMETER
SOHO

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A QUICK LOOK DENSITY/TEMPERATURE DIAGNOSTIC TOOL FOR CDS (SUMER)

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1 Overview

This document describes some simple "quick look" software intended for use with the SUMER and CDS instruments on the SOHO spacecraft. The software performs simple inversions of line ratio maps to produce density or temperature maps. It is available on anonymous ftp from the site hao.ucar.edu. Send email to `judge@hao.ucar.edu` or `paal.brekke@astro.uio.no` for instructions on how to access the data. General public release will await release of a later version after it has been field tested.

2 Description

One of the primary objectives of the CDS and SUMER instruments is to determine plasma parameters (e.g., temperatures, densities) from emission line spectra. While this formally is a rather nasty "inverse problem", there does appear to be a need for "quick and dirty" inversions for use at the SOHO observatory, while observers are collecting data. The software described here attempts to fulfil that need.

The frequency-integrated intensity of an optically thin line labeled i from a slab of thickness ΔZ cm can be written

$$I_i = \frac{h\nu_i}{4\pi} \int_{\Delta z} N_i A_i \, dz \tag{1}$$

where N_i is the population density of the upper level and A_i the Einstein A coefficient of the transition. Using the (unjustified but) standard assumptions of statistica equilibrium, Maxwell-Boltzmann distribution functions for electrons, the well known result is obtained that $N_i A_i$ is a strong function of electron temperature T_e and density N_e, and a weaker function of other factors. Thus $I_i \propto f_i(T_e, N_e, \alpha_i)$ where α_i accounts for the other factors (e.g. abundances). Replacing the integral over z with a 1-point quadrature, we can see that in general, the ratio of two lines I_i/I_j can be written

$$I_i/I_j \propto f_i(T_e, N_e, \alpha_i)/f_j(T_e, N_e, \alpha_j) \tag{2}$$

Where now T_e and N_e are understood to represent some "mean" values by virtue of the 1 point quadrature. If we choose lines of the same ionization stage then most of the dependences on α_i are identical for the two lines so we get

$$I_i/I_j \propto f_i(T_e, N_e)/f_j(T_e, N_e) \tag{3}$$

One more step is necessary. We must be able to identify "good temperature diagnostic line pairs", and "good density diagnostic line pairs", since the above equation is formally a function of the two variables T_e and N_e. These are line pairs for which I_i/I_j has a strong dependence on either T_e or N_e, but not both. Such pairs can be found, and some are listed in the red and blue books. Thus we get

$$
\begin{aligned}
I_i/I_j &\propto F(T_e, N_0) \quad \text{(A Temperature diagnostic)} \qquad (4)\\
&\propto G(N_e, T_0) \quad \text{(A Density diagnostic)} \qquad (5)\\
& \qquad (6)
\end{aligned}
$$

where N_0 and T_0 are values of density and temperature that must be chosen to be in the solar regime. **The procedures described below take observed values of I_i/I_j and translate those into values of T_e or N_e for specific line ratios of interest for CDS and SUMER, from detailed calculations of the emission coefficients $F(T_e, N_0)$ and $G(N_e, T_0)$.**[1]

3 Codes

There is a procedure `quick_inv.pro` that takes as input an observed line pair's intensity ratio I_i/I_j, the wavelengths of the two lines λ_i and λ_j, and an integer `type` which is 0 for a density-sensitive pair or 1 for a temperature sensitive pair. The procedure does the following: first it reads a (standard format) database file containing calculations of line emission coefficients ($\propto f_i(T_e, N_e)$), to look for matches of the line pair and `type`. Then, if successful, it performs an "inversion", i.e. it derives a single value of N_e (`type=0`) or T_e (`type=1`) for each value of I_i/I_j and returns an array of the same dimension as the input array I_i/I_j. By default, both the input and output arrays are plotted as is the relationship between the variable (i.e., N_e or T_e) and the line ratio. Pixels outside of the allowed range are flagged with yellow (below the allowed limit) or blue (above) in the default display. If the database search is unsuccessful

Here is a listing from the header of `quick_inv`

```
;+
; PROJECT:
;       HAOS-DIAPER
;
; NAME:
;       quick_inv
;
; Purpose     : Provide quick look density, temperature maps from line ratio maps
;
;       Details: To provide a displays of quick-look "inversions" of the ratio of line
;       intensities that are sensitive to either density or temperature (but not both
;       at the same time).  The procedure will by default display the input image,
;       the mapping between line ratio and the variable (electron density or
;       electron temperature).  A later version will display a term diagram of
;       the ion containing the two lines.
;
; EXPLANATION:
;
;       Given two lines at wavelengths w1 and w2 (units Angstrom),
```

[1]Interested users should contact `judge@hao.ucar.edu` for sources of data.

```
;       and an image imratio containing the ratio of the wavelength
;       integrated line intensities I(w1)/I(w2), this procedure will
;       find the densities corresponding to those ratios and will
;       display atomic data and the density image.
;
;
;       A database file is opened and searched for matches of the
;       calculation type (TYPE=0 or 1) and for matches of the
;       wavelengths w1, w2 +/- 0.1 angstrom. If such a match exists, line
;       emission coefficients are read from the database and the
;       ratio is constructed as a function of density (type = 0) or
;       temperature (type = 1).  That part of the emissivity ratio
;       that is monotonic centered around reasonable solar values of
;       density or temperature is retained and used to "invert" (via
;       a 1 point quadrature for the inversion, a simple linear
;       interpolation onto the ratio- variable plot) the intensity
;       ratios to make a map of density or temperature.
;
; CALLING SEQUENCE:
;       quick_inv, w1,w2,input,output [,oflags]
;
; INPUTS:
;       type     a flag used to tell the procedure if the line ratios are
;                expected to be:
;                type=0   density sensitive
;                type=1   temperature sensitive
;       w1       wavelength in Angstroms of line 1
;       w2       wavelength in Angstroms of line 2
;       input  the ratio of the intensity of line 1 to that of line 2
;                this is assumed to be a 2D array
; OPTIONAL INPUTS:
;       None.
;
; OUTPUTS:
;
;       output    a 2D array containing the density/temperature derived from
;                 the observed line ratios
; OPTIONAL OUTPUTS:
;
;       oflags    a 2D integer array showing the quality of the output array:
;                 oflags=0 no problems, oflags=-1 the line ratio lies too
;                 too close to the low density/temperature limit, oflags=+1 the
;                 line ratio lies too close to the high density/temperature limit
;
; KEYWORD PARAMETERS:
;
;       /help.        Will call doc_library and list header, and return
;       /termdiag     Will plot a term diagram (not available in this version)
```

```
;       range=range   Sets the range over which the variable is allowed to vary. For
;                     instance if type=0, and range=[1.e7,1.e11], the intensity image
;                     will only be mapped onto densities in the range 1.E7 to 1.E11
;       /noplot       If set, will make no displays (this is equivalent to calling
;                     the function  get_inv)
;       status=status 0=successful completion, other values will signify inversion faile
;
;
; RESTRICTIONS:
;       Will not plot a term diagram in version 1.0
;       Will only allow users to use ratios within a given ion
;       No treatement of blended lines is included.
;
```

4 Examples

The following IDL example will, given an array `obsratio` containing the ratio of intensities of the lines 1399.7 and 1401.1 of O IV, return a quick-look "density map" `imne`, with quality flags given by the variable `flags`. In the first case, the images are displayed and the functional dependence of the theoretical ratio on N_e is shown.

```
w1 = 1399.7     ;
w2 = 1401.1     ;
type=0          ; look for a density diagnostic pair in the database
;
;  First case, display all data
;
quick_inv,type,w1,w2,obsratio,imne,flags
;
;  Second case, the user displays obsratio and imne
;
quick_inv,type,w1,w2,obsratio,imne,flags,/noplot
;
window,1,title='Observed ratio'
exptv,obsratio
;
window,2,title='Corresponding density map'
exptv,imne
```