

ADAS506: GFT - graph and fit $G(T_e)$ functions

The program interrogates *GFT* files of type ADF20. The $G(T_e)$ function is extracted for a selected radiative transition of an ion. The data may be interpolated using cubic splines at selected electron temperatures. A minimax polynomial approximation is made to the interpolated data. The interpolated data are displayed and a tabulation prepared. The tabular and graphical output may be printed and includes the polynomial approximation.

Background theory:

One of the most widely used methods available for the interpretation of astronomical spectral intensities is the emission measure technique. This method is less familiar in spectroscopic studies of fusion plasma. However it and variants designed to determine impurity concentration, impurity variation in time and impurity influx are applicable in fusion.

The intensity of a spectral line from a column of optically thin plasma of cross-sectional area \mathbf{A} and due to a transition from upper level j to lower level k may be written as

$$I_{j \rightarrow k} = \frac{1}{4\pi\mathbf{A}} \iiint A_{j \rightarrow k} N_j dz dy dx \quad 6.6.1$$

where N_j denotes the population density of ions in the upper state j , $A_{j \rightarrow k}$ is the radiative transition probability for the transition and the integral is taken over the volume of the plasma viewed.

The excited population may be expressed in terms of the ground and metastable populations of the ionisation stage to which it belongs and to those of the adjacent higher ionisation stage by a quasi-equilibrium collisional radiative calculation as

$$N_j = \sum_{\sigma=1}^{M_z} \mathcal{F}_{j\sigma}^{(exc)} N_e N_\sigma + \sum_{v'=1}^{M_{z+1}} F_{jv'}^{(rec)} N_e N_{v'}^+ \quad 6.6.2$$

Usually contributions to the population of the excited state by excitation from the metastables of its own ionisation stage only need to be considered so that

$$N_j = \sum_{\sigma=1}^{M_z} \mathcal{F}_{j\sigma}^{(exc)} N_e N_\sigma \quad 6.6.3$$

In differential emission measure analysis, the assumption of ionisation balance is normally made. Although a time dependent ionisation could be used, the method would be specific to a particular model for the dynamic behaviour of the plasma and the universality of the emission measure technique would be lost. Thus it is convenient to write.

$$N_\sigma \equiv N_\sigma^{(z)} = \frac{N_\sigma^{(z)}}{N_{tot}} \frac{N_{tot}}{N_H} \frac{N_H}{N_e} N_e \quad 6.6.4$$

where the ratio $N_\sigma^{(z)} / N_{tot}$ is evaluated in equilibrium at the local temperature and density. For the solar plasma, the generally accepted assumption is that the abundance of the element N_{tot} / N_H does not vary through the depth of the atmosphere. Then gathering terms

$$A_{j \rightarrow k} N_j = \frac{N_{tot}}{N_H} N_e^2 G(T_e, N_e) \quad 6.6.5$$

where

$$G_{j \rightarrow k}(T_e, N_e) = A_{j \rightarrow k} \frac{N_H}{N_e} \sum_{\sigma=1}^{M_z} \mathcal{F}_{j\sigma}^{(exc)} \frac{N_\sigma^{(z)}}{N_{tot}} \quad 6.6.6$$

Then the spectral intensity may be written as

$$I_{j \rightarrow k} = \frac{1}{4\pi\mathbf{A}} \frac{N_{tot}}{N_H} \iiint G_{j \rightarrow k}(T_e, N_e) N_e^2 dz dy dx \quad 6.6.7$$

It is convenient to change the variable of the integral to electron temperature. However the atomic coefficient depends on both electron temperature and electron density so it is necessary to make some assumption about the relation between them. A common assumption is that the plasma pressure is constant over the relatively small range of temperature where the $G(T_e, N_e)$ function has significant values. In any event a model assumption is made even though the $G(T_e)$ function is usually written as function of temperature alone. Also introduce the concept of surfaces of constant temperature of which there may be more than one in the viewed volume. The intensity then may be rewritten as

$$I_{j \rightarrow k} = \frac{1}{4\pi\mathbf{A}} \frac{N_{tot}}{N_H} \int_{T_1}^{T_2} G_{j \rightarrow k}(T_e, N_e) \sum_l \int_{S_l(T_e)} |\nabla T_e|_l^{-1} N_e^2 dS_l dT_e \quad 6.6.8$$

The limits of the integral T_1 and T_2 are the minimum and maximum electron temperatures in the part of the atmosphere contributing to the spectrum. Introduce the differential emission measure, $\phi(T_e)$, defined by

$$\phi(T_e) = \frac{1}{\mathbf{A}} \sum_l \int_{S_l(T_e)} |\nabla T_e|_l^{-1} N_e^2 dS_l \quad 6.6.9$$

where the sum is taken over all l of the isothermal surfaces $S_l(T_e)$ and $|\nabla T_e|_l$ is the modulus of the temperature gradient perpendicular to the surface. By this definition $\phi(T_e)$ is the average value for the differential emission measure over the area viewed by the spectrometer. It is noted that $\phi(T_e)$ is the part of the integral it is sought to extract since it is the part which gives information about the structure of the atmosphere. The above analysis leads to the following expression for the spectral intensity

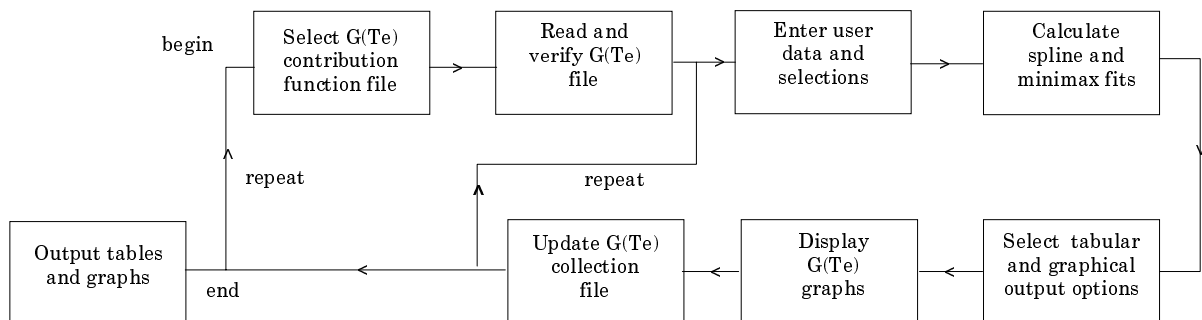
$$I_{j \rightarrow k} = \frac{1}{4\pi} \frac{N_{tot}}{N_H} \int_{T_1}^{T_2} G_{j \rightarrow k}(T_e, N_e) \phi(T_e) dT_e \quad 6.6.10$$

The program interrogates $G(T_e)$ data sets prepared according to the prescription of equation 6.6.6. Details of the model relating temperature, density, pressure and hydrogen to electron number densities are stored in the $G(T_e)$ datasets and this information is accessed simultaneously with the $G(T_e)$ in the interrogation. Interpolation of the $G(T_e)$ to arbitrary temperatures is done by cubic splines. This implies an implicit interpolation in the other model parameters. For completeness these model parameters are also explicitly interpolated as a function of temperature.

Program steps:

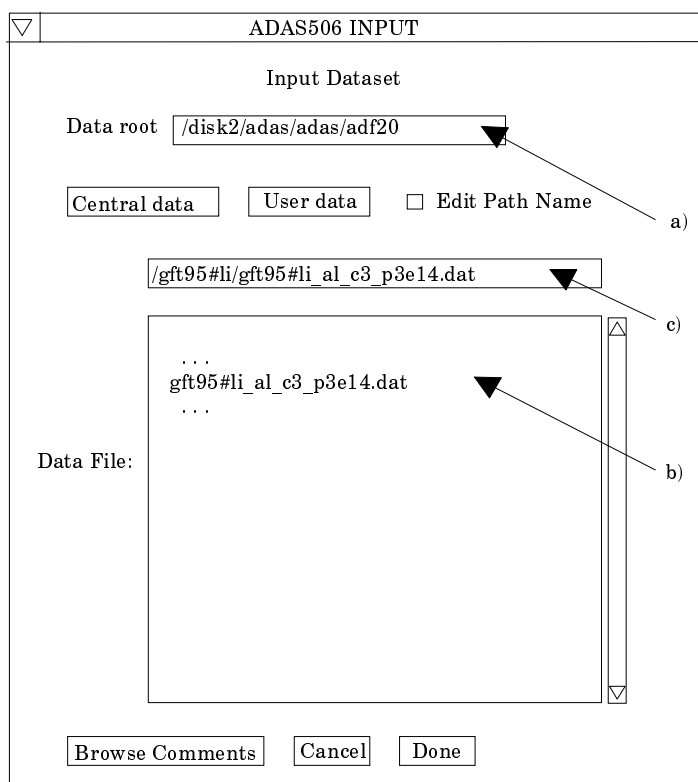
These are summarised in figure 6.6.

Figure 6.6



Interactive parameter comments:

The **file selection window** has the appearance shown below:.



1. Data root a) shows the full pathway to the appropriate data subdirectories. Click the *Central Data* button to insert the default central ADAS pathway to the correct data type. The appropriate ADAS data format for input to this program is ADF20 ('G(Te) files'). Click the *User Data* button to insert the pathway to your own data. Note that your data must be held in a similar file structure to central ADAS, but with your identifier replacing the first *adas*, to use this facility.
2. The Data root can be edited directly. Click the *Edit Path Name* button first to permit editing.
3. Available sub-directories are shown in the large file display window b). Scroll bars appear if the number of entries exceed the file display window size. They are named by iso-electronic sequence (eg. *gft95#li*). specific file names include a source identifier (eg. *al*) the specific ion symbol (eg. *c3*) and the pressure (eg. *p3e14*).
4. Click on a name to select it. The selected name appears in the smaller selection window c) above the file display window. Then the individual datafiles are presented for selection. Datafiles all have the termination *.dat* (eg. *gft95#li_al#c3_p3e14.dat*).
5. Once a data file is selected, the set of buttons at the bottom of the main window become active.
6. Clicking on the *Browse Comments* button displays any information stored with the selected datafile. It is important to use this facility to find out what has gone into the dataset and the attribution of the dataset. The possibility of browsing the comments appears in the subsequent main window also.
7. Clicking the *Done* button moves you forward to the next window. Clicking the *Cancel* button takes you back to the previous window

The **processing options window** has the appearance shown below.

ADAS506 PROCESSING OPTIONS

Title for run

Data File Name : /home/lanafam/adas/adf20/gft95#li/gft95#li_al_c3_p3e14.dat

Browse comments

Number of Electron Impact Transition s : 29
Number of Index Energy Levels : 15

Polynomial fitting

◊ Fit Polynomial value % :

Select Transition

TRANSITION INDEX	-----UPPER LEVEL----- INDEX	-----DESIGNATION	-----LOWER LEVEL----- INDEX	-----DESIGNATION	APPROXIMATE WAVELENGTH	SPECTROSCOPIC WAVELENGTH
1	1	2s1 (2)S(0.5)	1	2p1 (2)P(0.5)	1550.800	0.000
1	1	2s1 (2)S(0.5)	1	2p1 (2)P(0.5)	1550.800	0.000

a)

Select Temperature for Output File ◊

Output Electron Temperatures

Index	Output	Input
1	1.000E+00	1.000E+00
2	2.000E+00	2.000E+00
3	5.000E+00	5.000E+00
4	1.000E+01	1.000E+01
5	2.000E+01	2.000E+01

Temperature units : eV

Edit Table

Default Temperature values

Edit the processing options data and press Done to proceed

1. Transitions for which G(Te) data are available in the data set are displayed in the line list display window. This is a scrollable window using the scroll bar to the right of the window. Click anywhere on the row for a line to select it. The selected transition appears in the selection window a) just above the line list display window.
2. Your settings of electron temperatures (output) are shown in the temperature display window d). The temperature values at which the G(Te) coefficients are stored in the datafile (input) are also shown for information.
3. The program recovers the output temperatures you used when last executing the program. Pressing the *Default Temperature values* button inserts a default set of temperatures equal to the input temperatures
4. The Temperature Values are editable. Click on the *Edit Table* button if you wish to change the values. A 'drop-down' window, the ADAS Table Editor window: It follows the same pattern of operation as described in bulletin.
5. Clicking the *Done* button causes the next output options window to be displayed. Remember that *Cancel* takes you back to the previous window.

The **output options window** has the appearance shown below.

ADAS506 OUTPUT OPTIONS

Data file name : /home/lanzafam/adas/adf20/gft95#li/gft95#li_al#c3_p3e14.dat

Browse Comments

Graphical Output Default Device

Graph Title

Explicit Scaling

X-min X-max

Y-min Y-max

Enable Hard Copy Replace

File name :

Text Output Replace

File name :

Collection File Replace

File name :

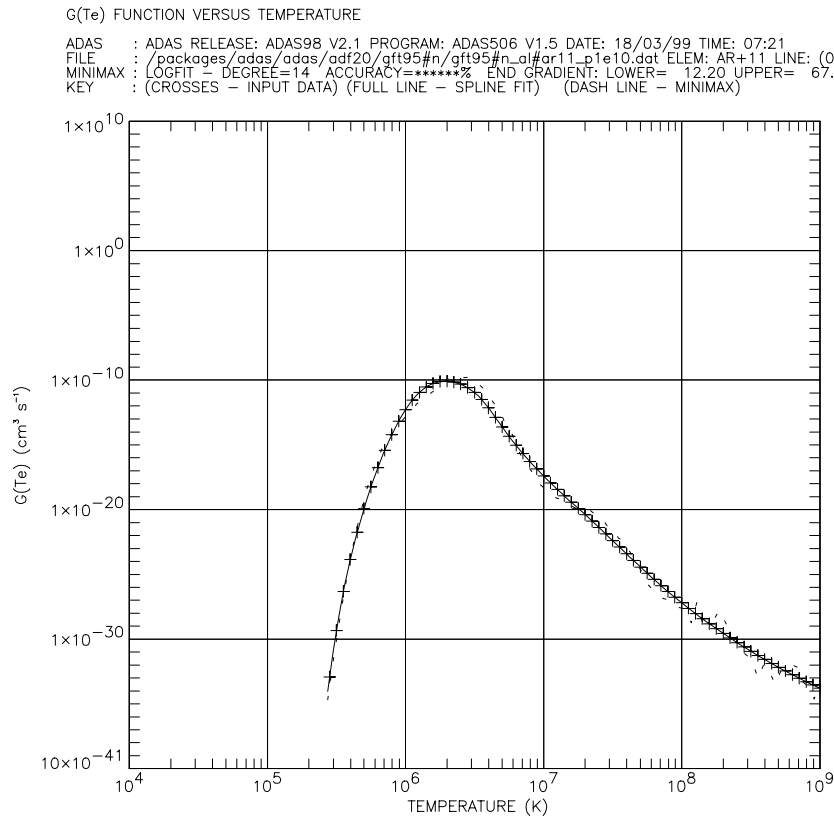
a)

6. The graph is displayed in a following graphical output window.
7. Writing to the collection file is activated by clicking the *Collection File* button at a). The operation is slightly different from the usual text output. The collection file is composed of blocks of data for each spectrum line. Each block includes a header line which enables the code to construct an indexed list of lines present in the collection file. A line which is already present in the collection is replaced if the *Replace* button is activated, otherwise it is disallowed. Thus the G(Te) collection file contains any one line only once.

Illustration:

Figure 6.6a shows the G(Te) function for 1054.7 Å line of ArXII. The GFT data set was prepared for a constant pressure model at 3×10^{10} K cm⁻³. The model includes the variation of the ratio N_H / N_e in the solar atmosphere with temperature in the G(Te) functions. Table 6.6a provides a text summary of the interrogation. Table 6.6b is the compact collection file prepared for differential emission measure analysis (ADAS601).

Figure 6.6a



The tabulation is given in table 6.6a. For completeness, interpolation with temperature of the model electron density, electron pressure and N_H / N_e is given in the table.

Table 6.6a

ADAS RELEASE: ADAS98 V2.1 PROGRAM: ADAS506 V1.5 DATE: 18/03/99 TIME: 07:21

*** TABULAR OUTPUT FROM G(TE) FUNCTION FILES INTERROGATION PROGRAM: ADAS506 - DATE: 18/03/99 ***

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G(TE) CONTRIBUTION FUNCTIONS AS A FUNCTION OF TEMPERATURE

DATA GENERATED USING PROGRAM: ADAS506

/packages/adas/adas/adf20/gft95#n/gft95#n_al#ar11_p1e10.dat ELEM: AR+11 LINE: (

NUCLEAR CHARGE (Z0) = 18
 RECOMBINING ION CHARGE (Z1) = 12
 RECOMBINED ION CHARGE (Z) = 11

LEVEL	CONFIGURATION	QUANTUM NUMBERS		
		2S+1	L	(WI-1)/2
2 - UPPER	2S22P3	2	2	1.5
1 - LOWER	2S22P3	4	0	1.5

TRANSITION WAVELENGTH (APPROX.) = 1054.7 A
 TRANSITION WAVELENGTH (EXACT) = 0.0 A

KELVIN	TEMPERATURE	KELVIN/Z1**2	GFT CM3 S-1	DENS CM-3	PRESS KCM-3	NH/NE
	EV					
8.91D+04	7.68D+00	6.19D+02	1.00D-99	1.12D+05	9.98D+09	8.55D-01
1.00D+05	8.62D+00	6.94D+02	3.18D-96	1.00D+05	1.00D+10	8.49D-01
1.12D+05	9.65D+00	7.78D+02	1.69D-85	8.91D+04	1.00D+10	8.42D-01
1.26D+05	1.09D+01	8.75D+02	5.62D-76	7.94D+04	1.00D+10	8.35D-01
5.01D+08	4.32D+04	3.48D+06	6.71D-33	2.00D+01	1.00D+10	8.27D-01
5.62D+08	4.84D+04	3.90D+06	3.44D-33	1.78D+01	1.00D+10	8.27D-01

```

6.31D+08    5.44D+04    4.38D+06    1.79D-33    1.58D+01    9.97D+09    8.27D-01
7.08D+08    6.10D+04    4.92D+06    9.46D-34    1.41D+01    9.98D+09    8.27D-01
7.94D+08    6.84D+04    5.51D+06    5.10D-34    1.26D+01    1.00D+10    8.27D-01
8.91D+08    7.68D+04    6.19D+06    2.81D-34    1.12D+01    9.98D+09    8.27D-01
1.00D+09    8.62D+04    6.94D+06    1.57D-34    1.00D+01    1.00D+10    8.27D-01
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0
MINIMAX POLYNOMIAL - TAYLOR COEFFICIENTS: LOG10(GFT) vs. LOG10(TEMP<kelvin>)
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A( 1) = 1.937181501D+11    A( 2) = -4.050067146D+11
A( 3) = 3.918033147D+11    A( 4) = -2.324602981D+11
A( 5) = 9.449986067D+10    A( 6) = -2.784466426D+10
A( 7) = 6.132657037D+09    A( 8) = -1.025641199D+09
A( 9) = 1.308892036D+08    A(10) = -1.268427661D+07
A(11) = 9.188618694D+05    A(12) = -4.825064973D+04
A(13) = 1.736243958D+03    A(14) = -3.832293697D+01
A(15) = 3.914702988D-01

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LOGFIT - DEGREE=14 ACCURACY=*****% END GRADIENT: LOWER= 12.20 UPPER= 67.89
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Table 6.6b

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AR+11 /ITRANS= 1/NTEMP= 82/APPWAV= 1054.700/SPWAV= 0.000/
/packages/adas/adas/adf20/gft95#n/gft95#n_al#ar11_p1e10.dat
4.95 5.00 5.05 5.10 5.15 5.20 5.25 5.30 5.35 5.40 5.45 5.50 5.55 5.60 5.65 5.70 5.75 5.80 5.85 5.90 5.95
6.00 6.05 6.10 6.15 6.20 6.25 6.30 6.35 6.40 6.45 6.50 6.55 6.60 6.65 6.70 6.75 6.80 6.85 6.90 6.95 7.00
7.05 7.10 7.15 7.20 7.25 7.30 7.35 7.40 7.45 7.50 7.55 7.60 7.65 7.70 7.75 7.80 7.85 7.90 7.95 8.00 8.05
8.10 8.15 8.20 8.25 8.30 8.35 8.40 8.45 8.50 8.55 8.60 8.65 8.70 8.75 8.80 8.85 8.90 8.95 9.00
1.0000D-99 3.1770D-96 1.6920D-85 5.6200D-76 1.5710D-67 4.7530D-60 2.0030D-53 1.4620D-47 2.2820D-42
9.3320D-38 1.1800D-33 4.6130D-30 4.8420D-27 1.4310D-24 1.7670D-22 1.2290D-20 5.5550D-19 1.7290D-17 3.8180D-
16 6.0220D-15 6.7520D-14 5.2970D-13 2.8820D-12 1.0900D-11 2.8920D-11 5.4780D-11 7.6540D-11 8.2220D-11
7.0060D-11 4.8170D-11 2.6400D-11 1.0940D-11 3.2300D-12 7.0840D-13 1.3270D-13 2.4250D-14 4.6530D-15 9.6250D-
16 2.1560D-16 5.2340D-17 1.3740D-17 3.8630D-18 1.1520D-18 3.5890D-19 1.1530D-19 3.7660D-20 1.2360D-20
4.0350D-21 1.3030D-21 4.1520D-22 1.3080D-22 4.0670D-23 1.2490D-23 3.8350D-24 1.1890D-24 3.7560D-25 1.2160D-
25 4.0270D-26 1.3640D-26 4.7500D-27 1.7090D-27 6.3270D-28 2.3960D-28 9.3010D-29 3.7090D-29 1.5200D-29
6.3870D-30 2.7520D-30 1.2140D-30 5.4650D-31 2.5040D-31 1.1660D-31 5.5240D-32 2.6730D-32 1.3260D-32 6.7100D-
33 3.4420D-33 1.7900D-33 9.4570D-34 5.0990D-34 2.8100D-34 1.5680D-34
XX

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Notes: