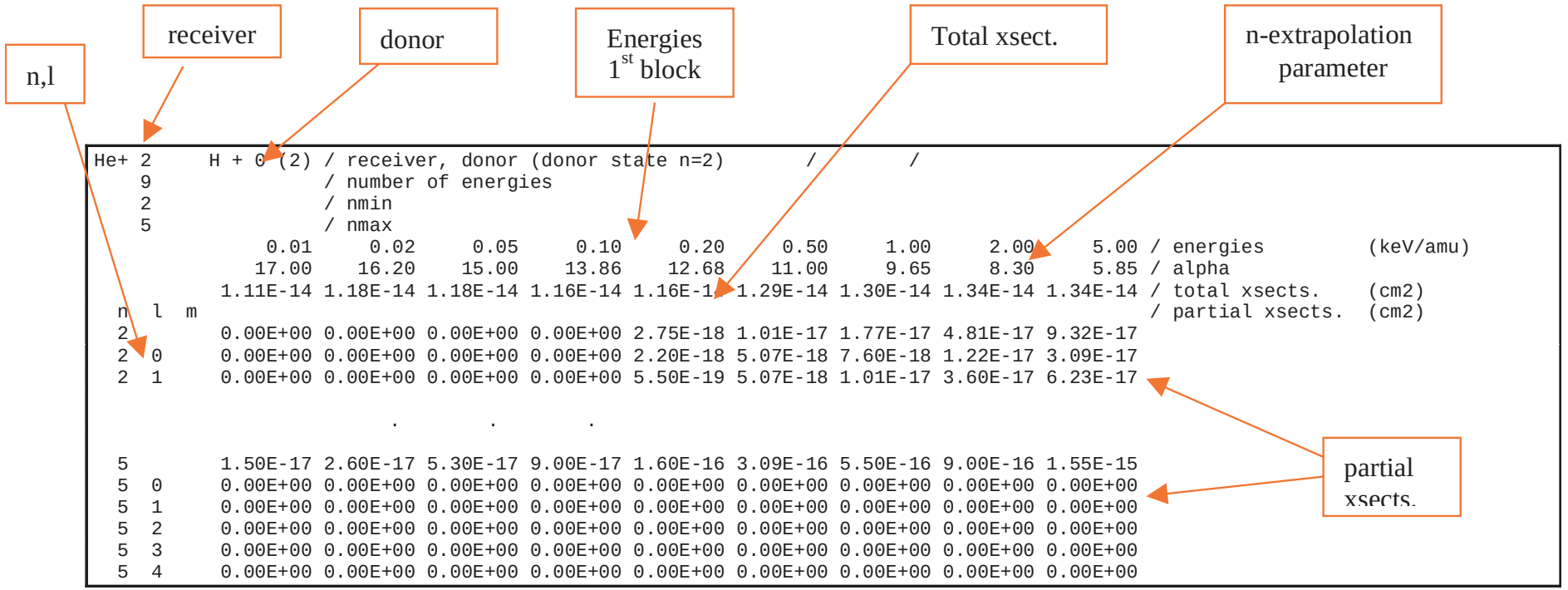
Part I : Charge exchange spectroscopy

- Interrogating state selective charge exchange cross-sections using ADAS301.
- Interrogating CXS effective emission coefficients using ADAS303.
- Calculating and examining effective emission coefficients using ADAS308.

Interrogating charge exchange cross-sections

- Datasets of class ADF01 contain state selective charge exchange xsect. (qcx) data as a function of energy.
- These data for bare nucleus light impurity receivers into nl-shells in general.
- The donors may be H, He or Li and can include donation from ground state and excited state. There are separate data sets for each excited donor state.
- Code ADAS301 interrogates ADF01 data sets and displays results at energies of your choice.

ADF01 charge exchange cross-sections

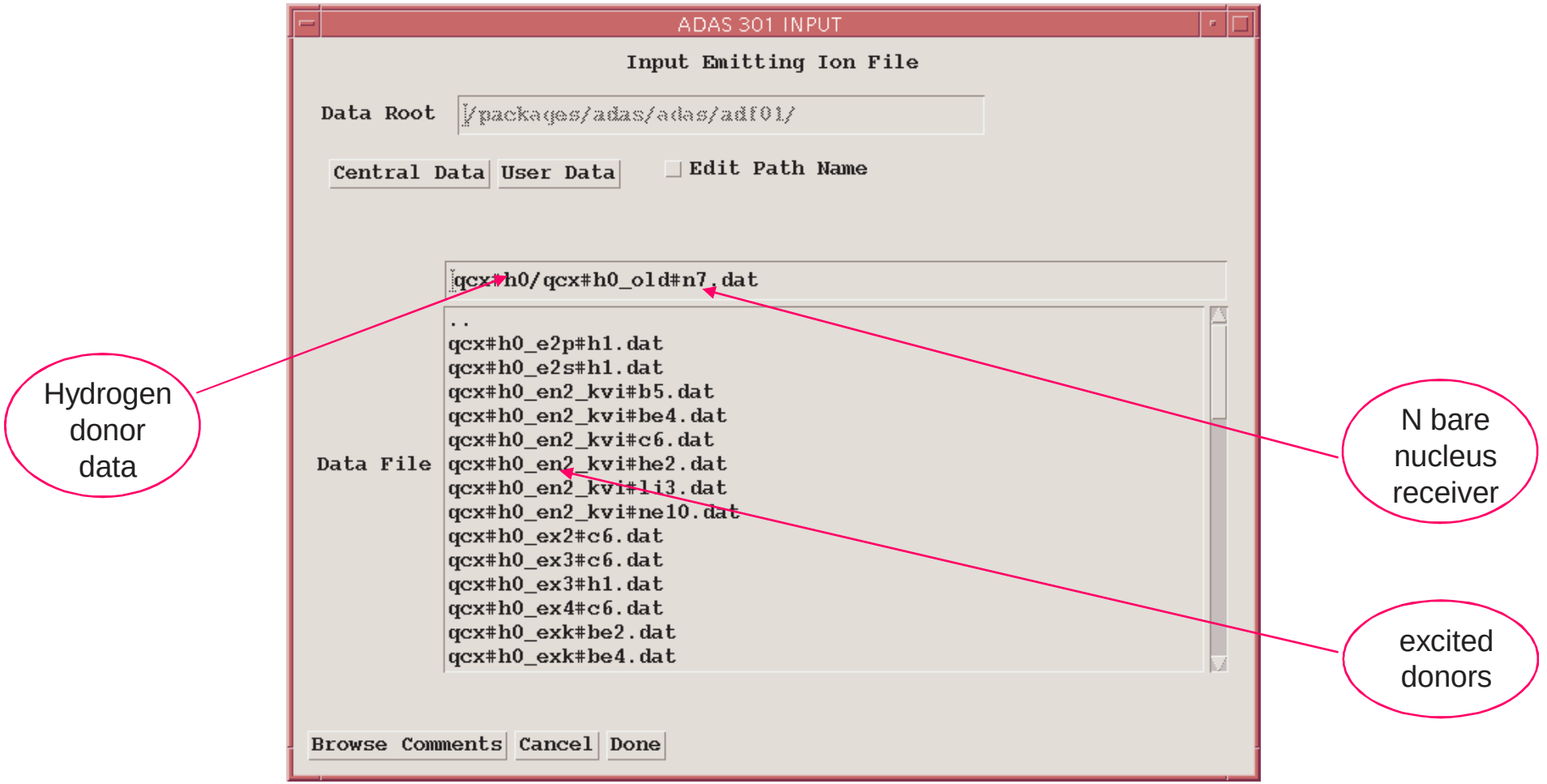



```
He+ 2     H + 0 (2) / receiver, donor (donor state n=2)       /       /
    9               / number of energies
    2               / nmin
    5               / nmax
                0.01     0.02     0.05     0.10     0.20     0.50     1.00     2.00     5.00 / energies         (keV/amu)
               17.00    16.20    15.00    13.86    12.68    11.00     9.65     8.30     5.85 / alpha
            1.11E-14 1.18E-14 1.18E-14 1.16E-14 1.16E-14 1.29E-14 1.30E-14 1.34E-14 1.34E-14 / total xsects.    (cm2)
  n   l  m                                                                                   / partial xsects.  (cm2)
  2         0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.75E-18 1.01E-17 1.77E-17 4.81E-17 9.32E-17
  2  0      0.00E+00 0.00E+00 0.00E+00 0.00E+00 2.20E-18 5.07E-18 7.60E-18 1.22E-17 3.09E-17
  2  1      0.00E+00 0.00E+00 0.00E+00 0.00E+00 5.50E-19 5.07E-18 1.01E-17 3.60E-17 6.23E-17

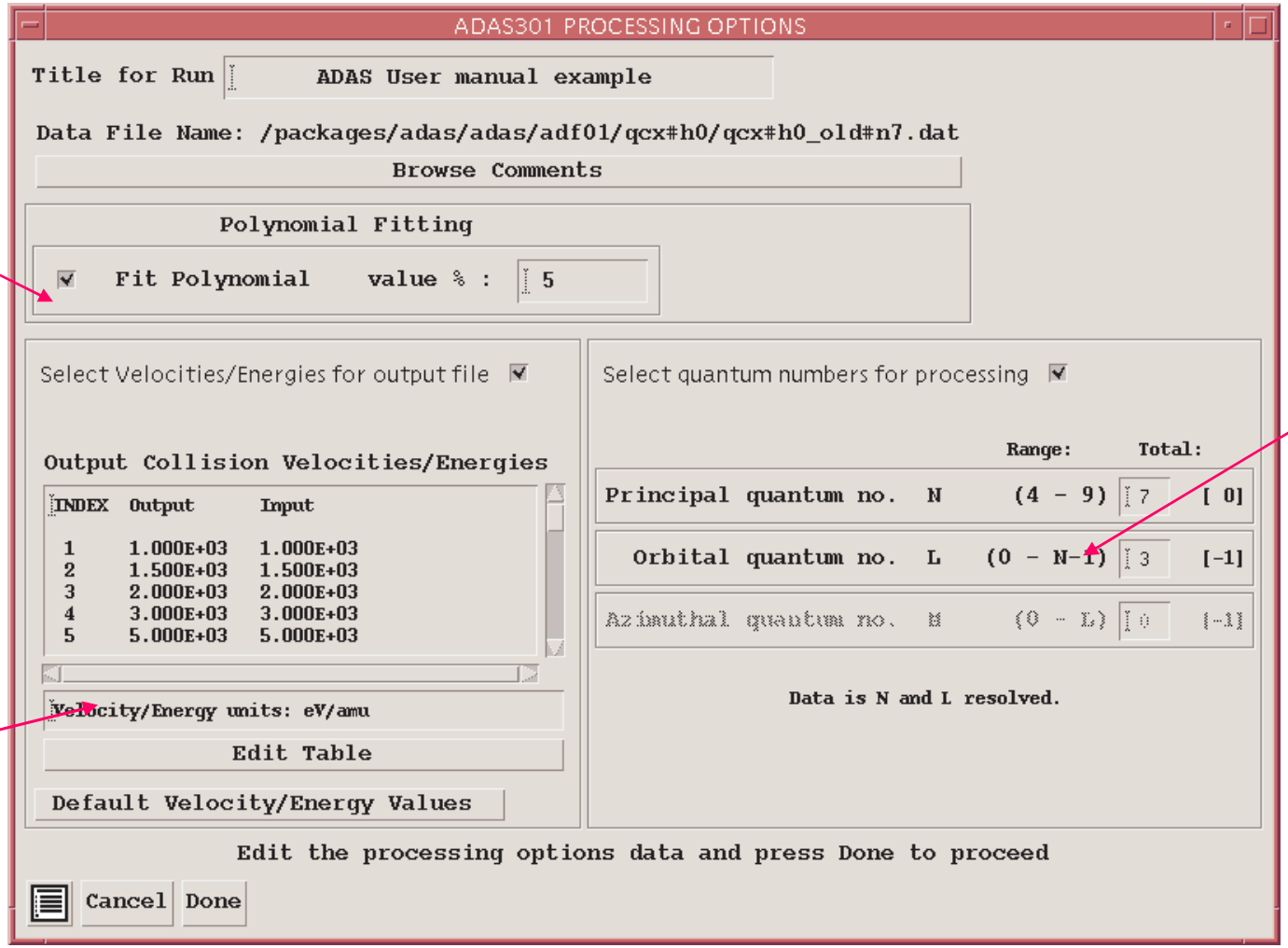
                          .        .        .

  5         1.50E-17 2.60E-17 5.30E-17 9.00E-17 1.60E-16 3.09E-16 5.50E-16 9.00E-16 1.55E-15
  5  0      0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5  1      0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5  2      0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5  3      0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
  5  4      0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
```

ADAS301 input



ADAS302 Processing

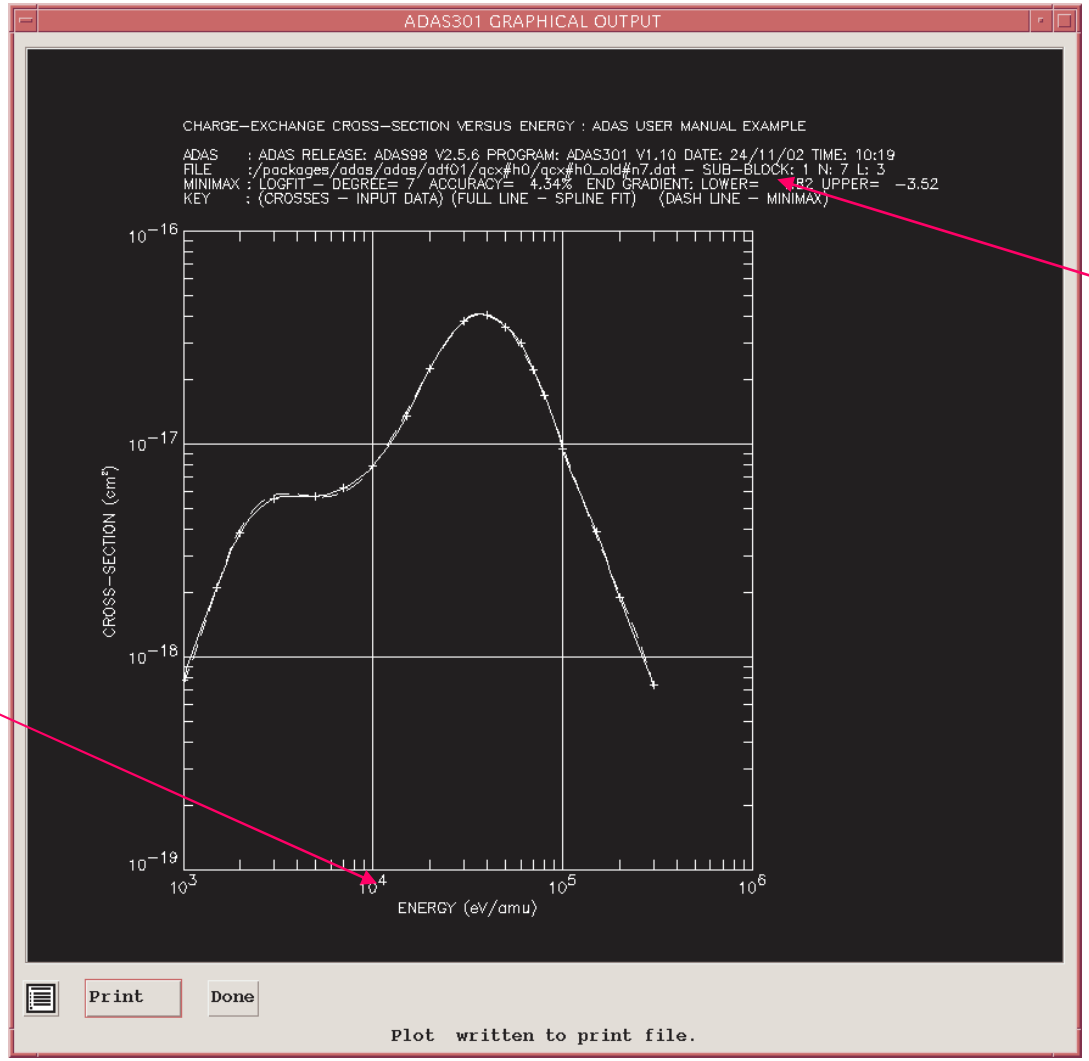


Polynomial fit

Specify energies & units

select partial xsect

ADAS301 graph



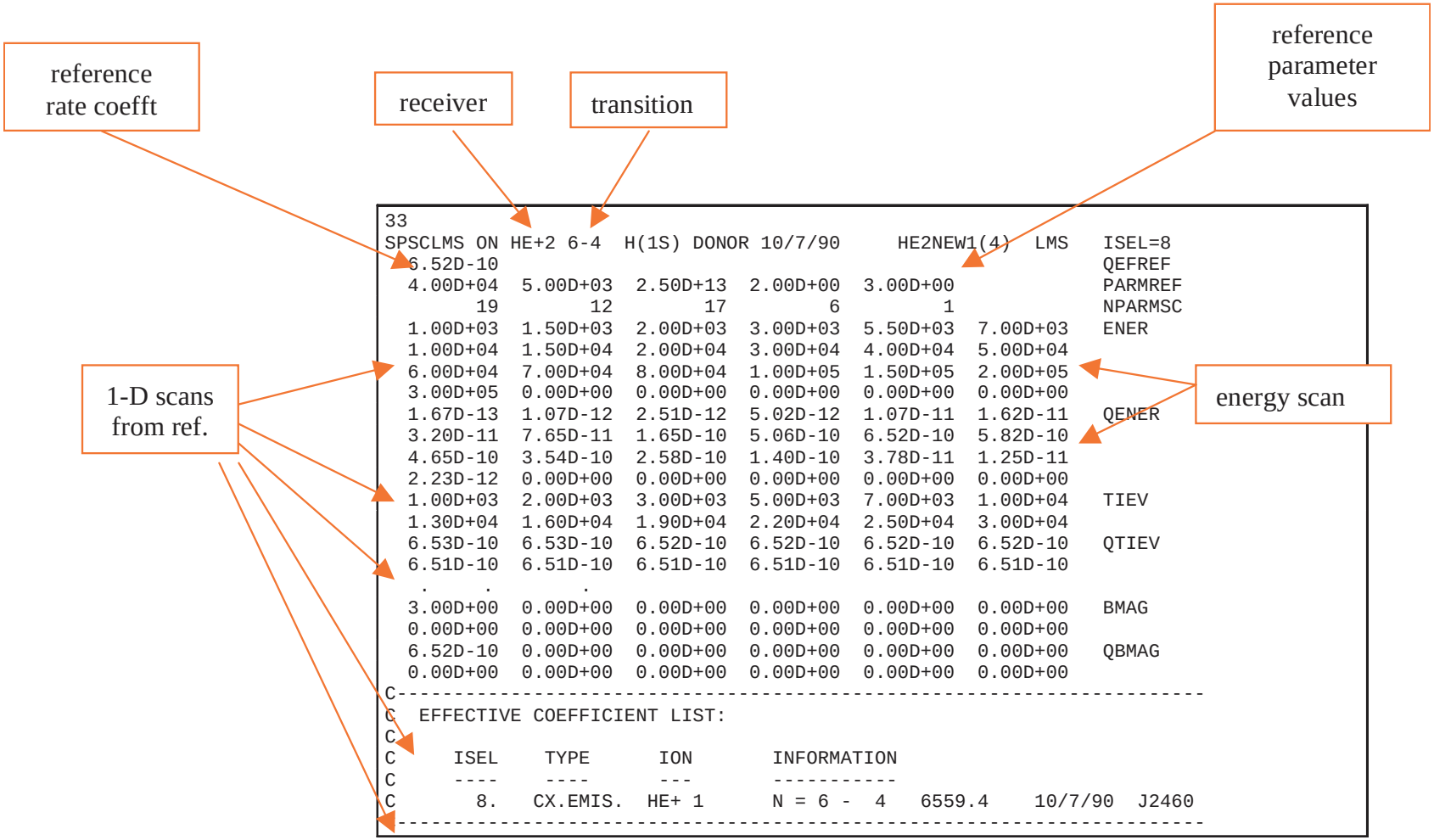
specification of extracted xsect.

graph is a function of energy

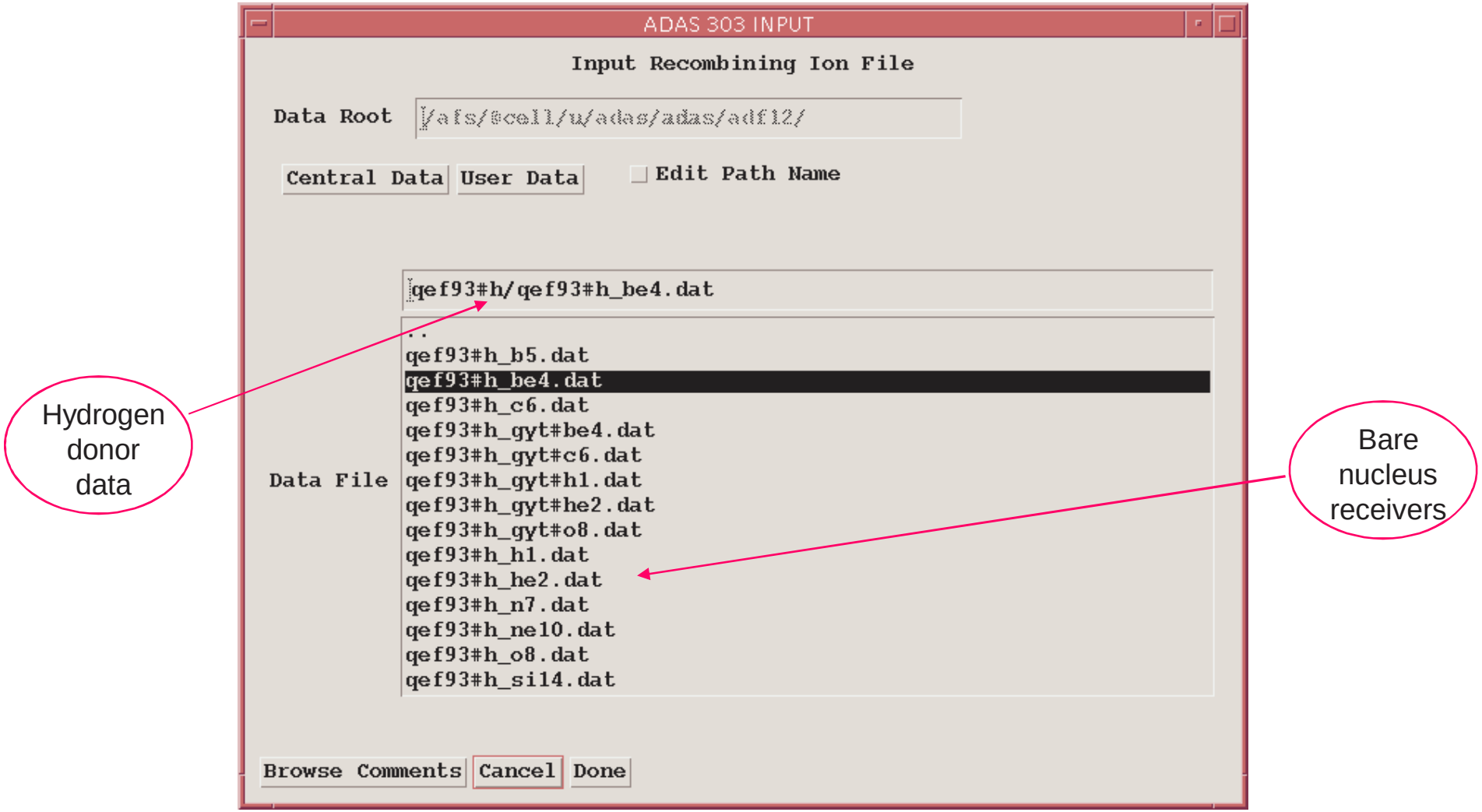
Interrogating CXS effective emission coefficients

- Datasets of class ADF12 contain CXS effective emission (qef) data as a function of beam and plasma parameters.
- These coefficients include the effect of collisional redistribution of nl-substate populations of the receiver ion in the plasma.
- The individual components of the n->n' CX transition are not resolvable for bare nucleus receivers so only whole transition arrays are given.
- Code ADAS303 interrogates ADF12 data sets and displays results at beam and plasma conditions of your choice.

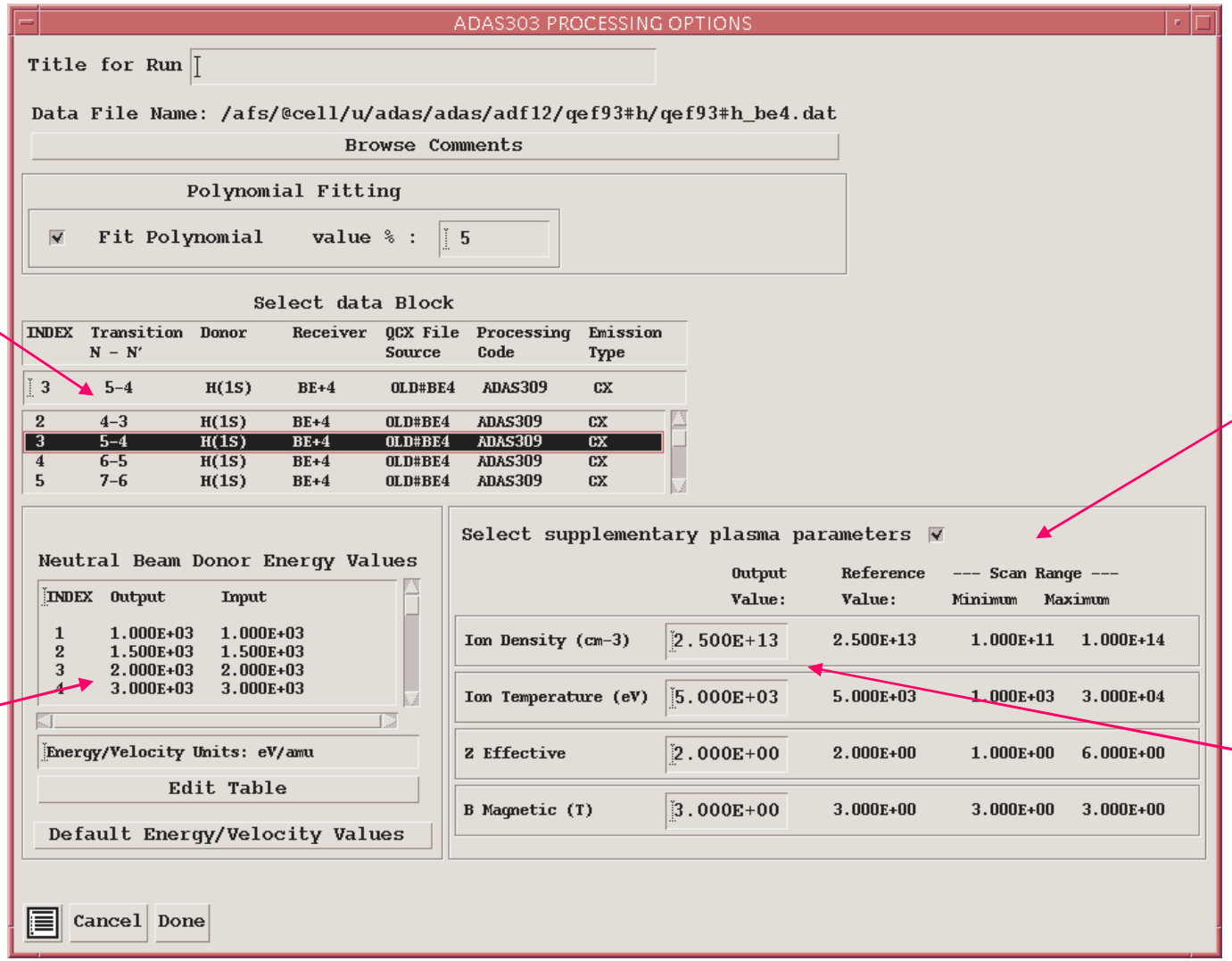
ADF12 charge exchange cross-sections



ADAS303 input



ADAS303 Processing



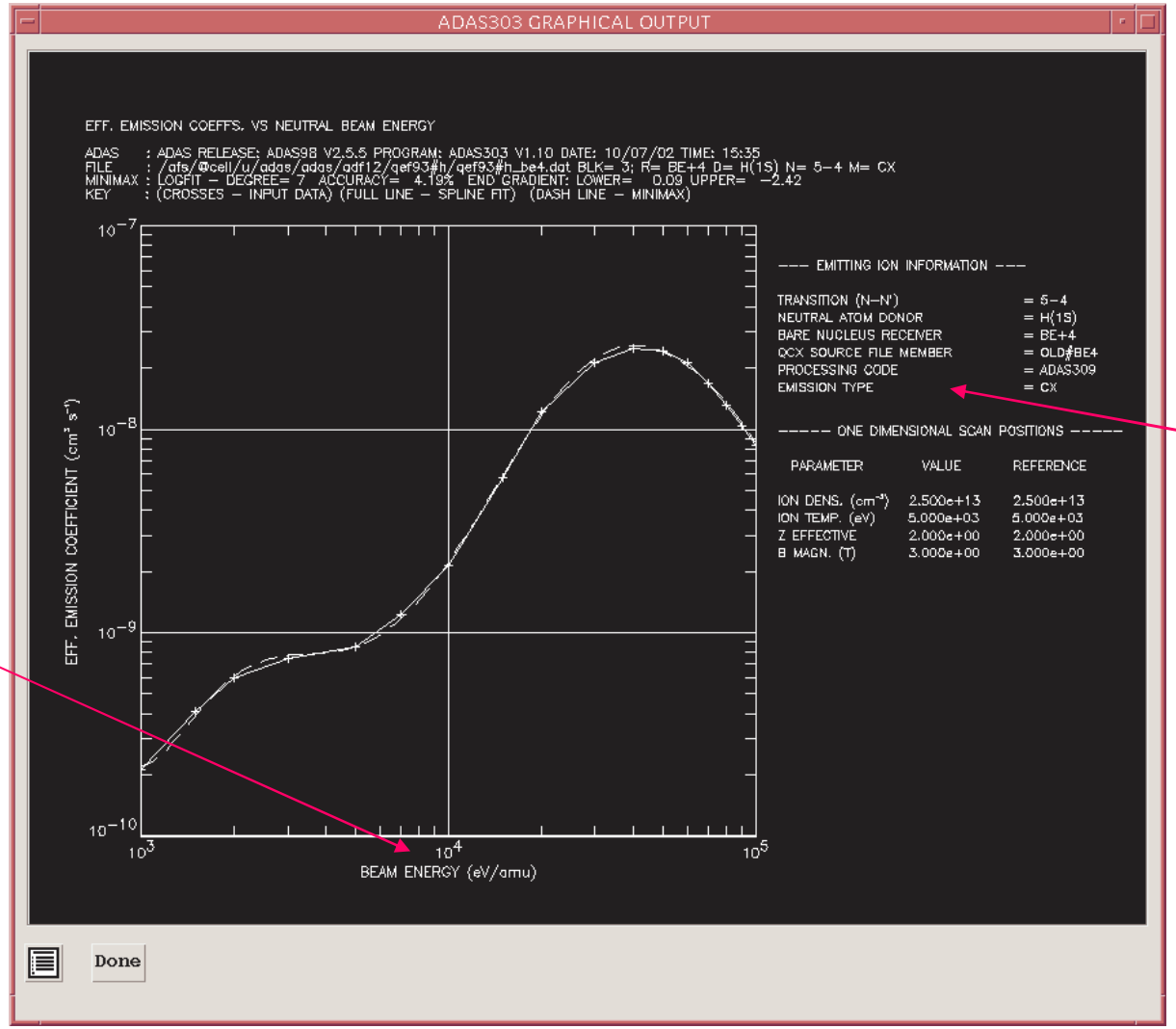
Select transition

Specify donor energies

Scan range and reference

Select plasma conditions

ADAS303 graph



graph is a function of beam energy

plasma and beam conditions for graph

Calculating CXS effective emission

- Datasets of class ADF01 state selective charge exchange cross-section data for capture by fully ionised ions.

- Code ADAS308 computes effective emission coefficients, predicts CXS line positions and profiles and deduces the beam plasma emission measure.

Calculating CXS effective emission (contd.)

- The driving reactions are

$$X^{+z_0} + D^0_{beam}(1s) \rightarrow X^{+z_0-1}(nl) + D^+_{beam}$$

- The effective emission coefficient for n-n’ transition is

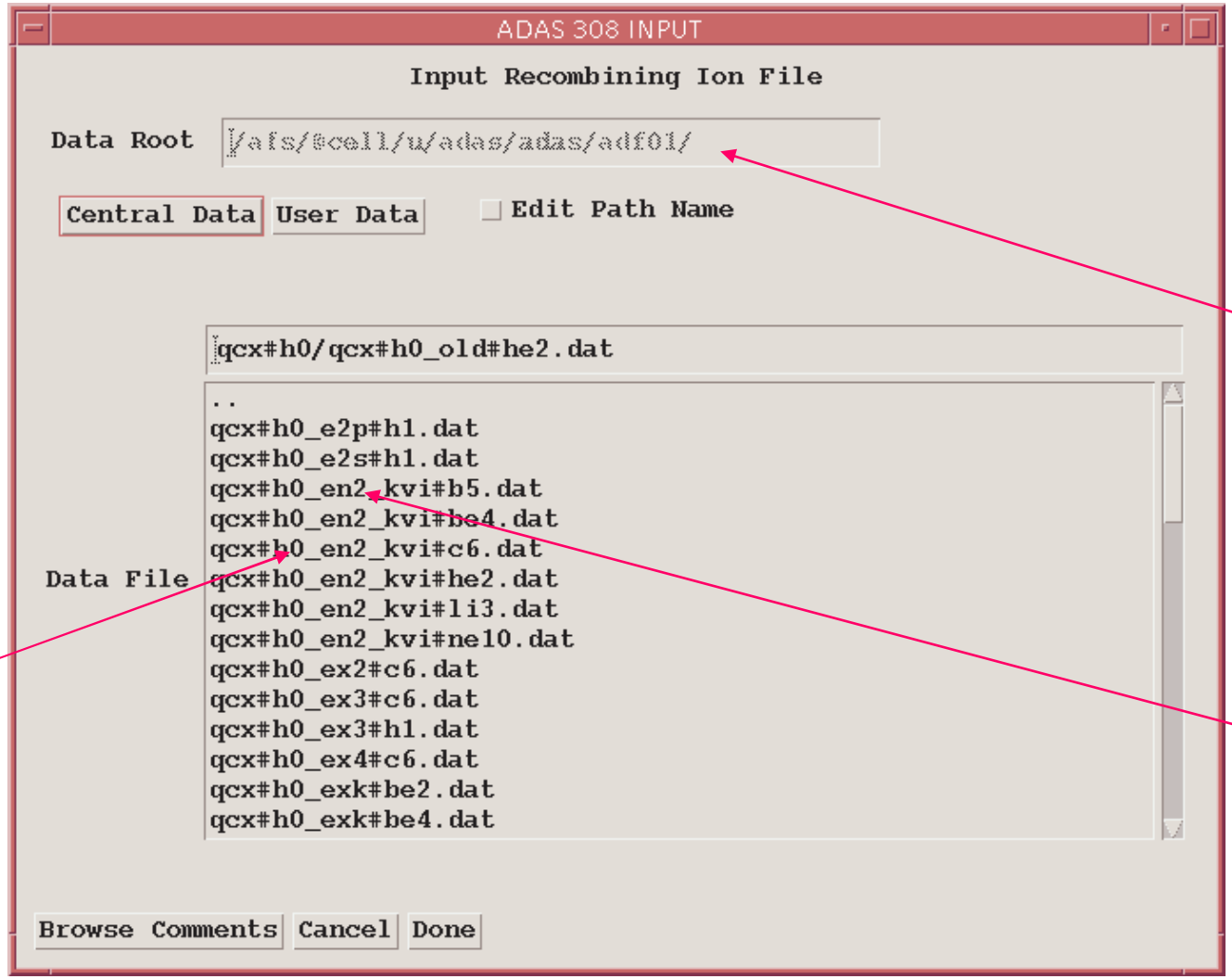
$$q^{(eff)}_{n\rightarrow n'} = \sum_{l,l'} A_{nl\rightarrow n'l'}(N^{(z_0-1)}_{nl} / N_D N^{(z_0)})$$

- Thus a collisional-radiative, resolved-nl population calculation is required to determine the effective emission coefficients.

Calculating CXS effective emission (contd.)

- File selection
  - » The fundamental state selective charge exchange x-sect data is format ADF01. These data are resolved into the nl shells of the receiver.
  - » Note that there are sub-directories for different donors and separate data sets for ground and excited donor states.
- Processing options
  - » *Beam parameter, observed spectrum lines and required emssivity predictions must be entered using Table Editor.*
  - » *Then plasma conditions must be entered.*
  - » *Finally model for emission measure is chosen.*
- Output options
  - » Graphical display of the spectral position, intensity and shape of a designated n-n' transition is given.
  - » Tabulations of predicted intensities of other lines are given together with the estimated emission measure.

ADAS308 Input



fundamental state selective CX x-sects.

hydrogen beam donor data

excited (n=2) beam donor data

Calculating CXS effective emission (contd.)

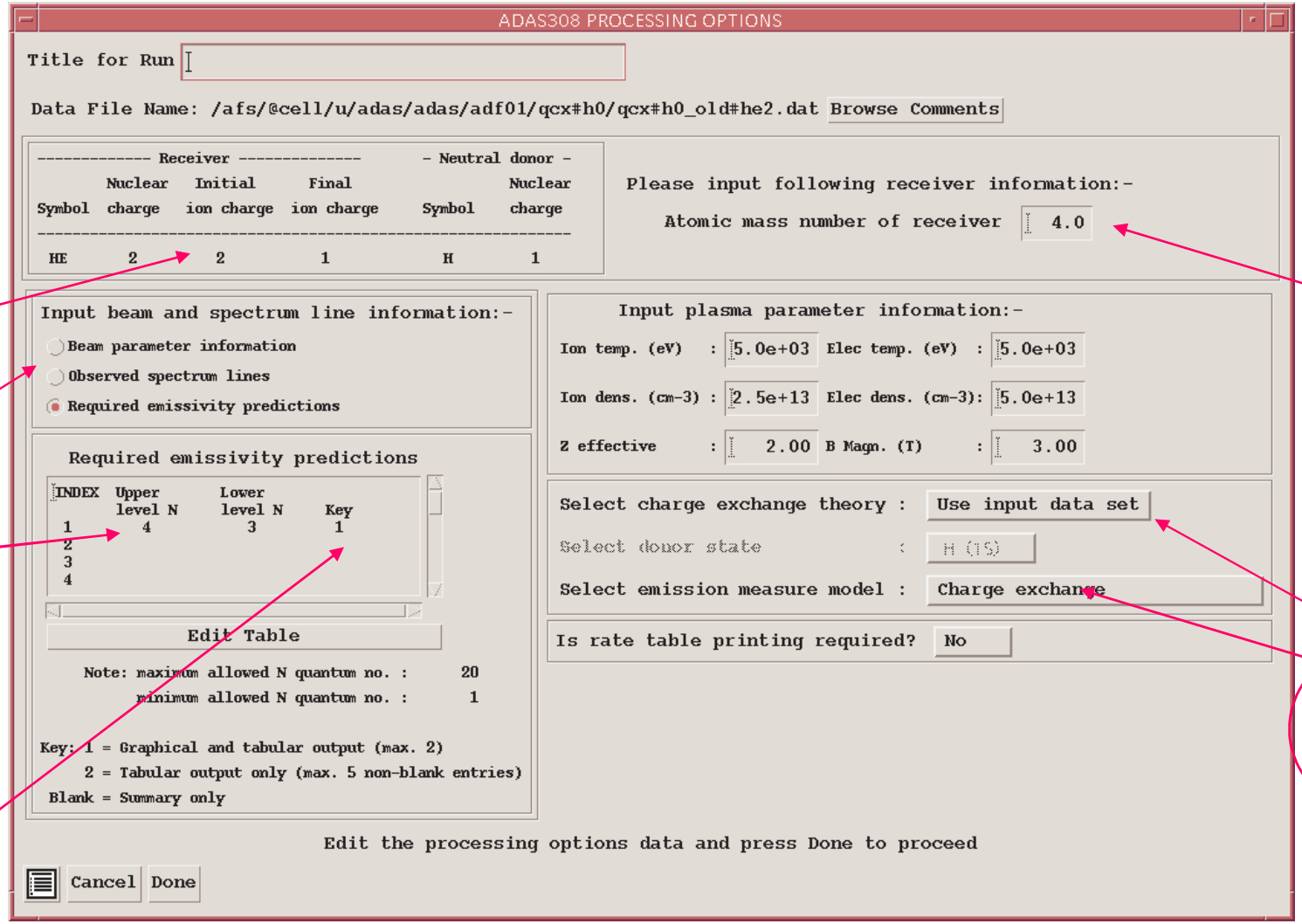
- ADAS308 is designed to do more than solve for the effective emission coefficients, qef.

- The program computes the qef and solves for the emission measure given the line of sight intensity in a charge exchange line as

$$I_{n\to n'}^{(z_0-1)} \approx q_{n\to n'}^{(eff)} \int N_D N^{(z_0)} ds$$

- If more than one charge exchange line intensity, with different upper levels, the code can assess the consistency between experimental and theoretical data. ADAS308 casts this onto the consistency of the ADF01 total n-shell capture with observation.
- Most use of ADAS308 has been directed at qef and its components alone.

ADAS308 processing



information from data set

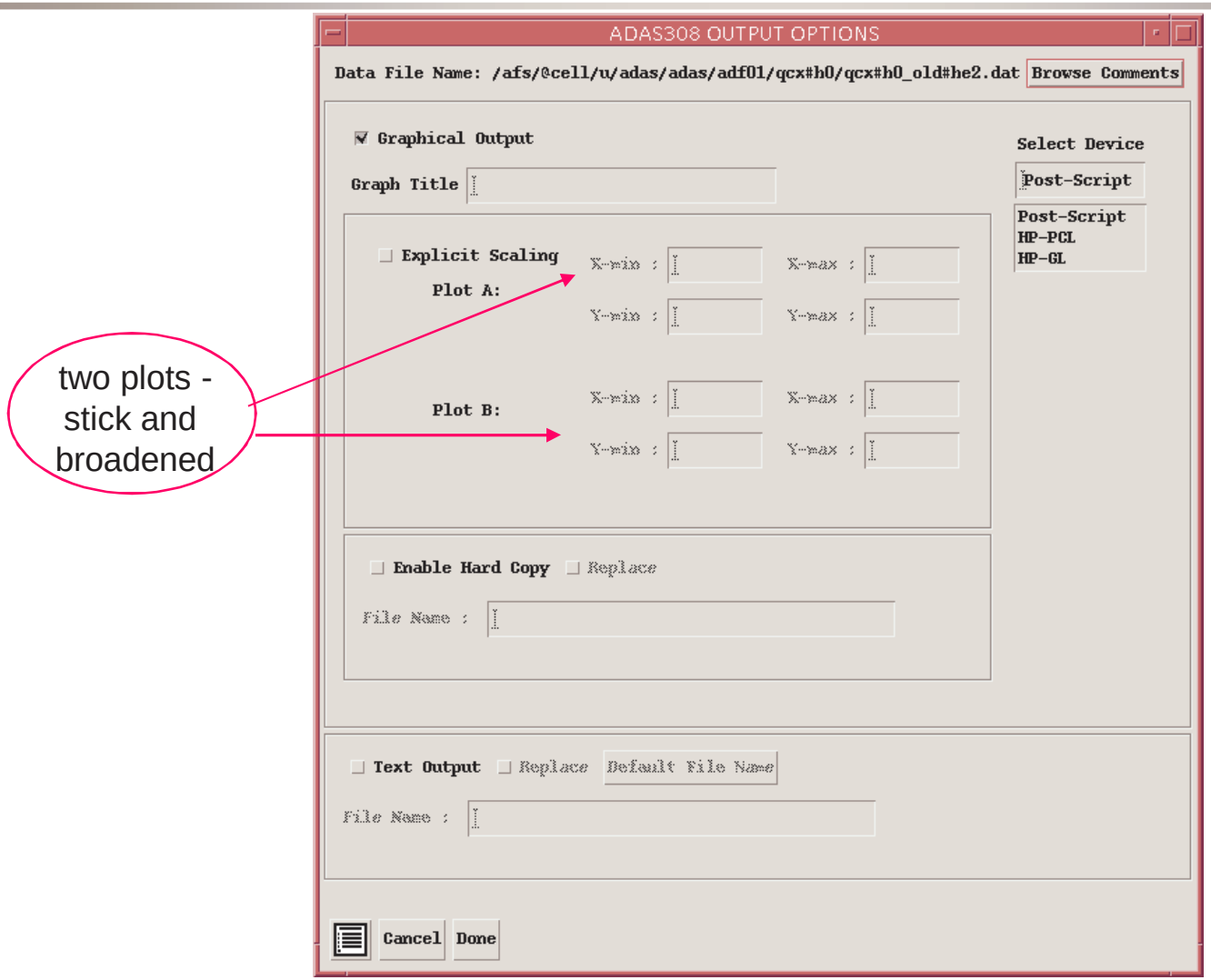
various data required - appropriate is table displayed

key determines tables and graphs

masses required for ion collisions

model choice - usually input data and CX

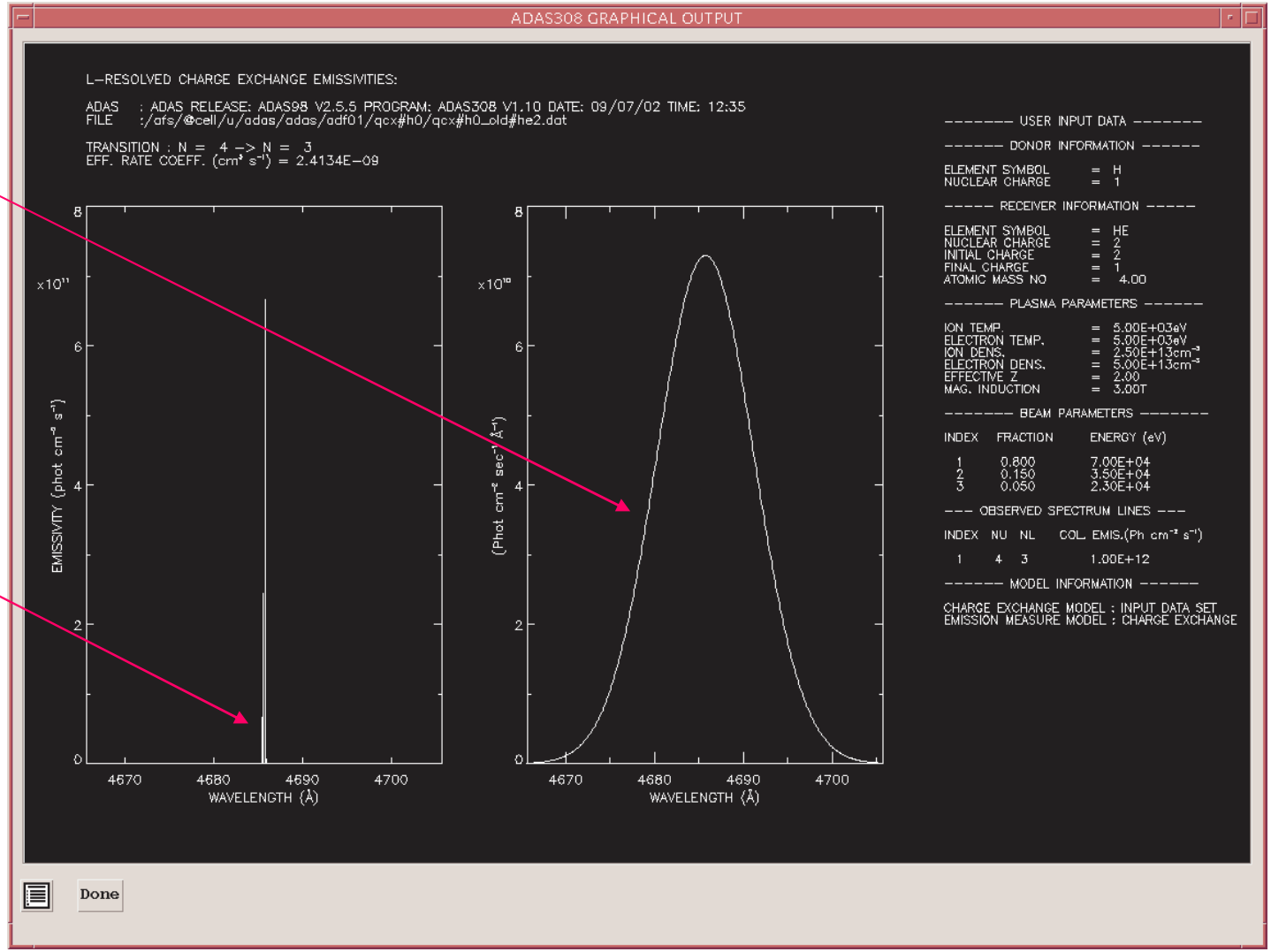
ADAS308 output



ADAS308 graph

doppler broadened n->n' line

exact component wavelengths and relative emissivities



Mass production of CX effective emission coeffts.

- ADAS309 is the mass production code for the effective emission coefficients for charge exchange lines.
- The user input is similar to that for ADAS308 but there is no graphical output, nor does it attempt the inversion solution.
- Many transitions can be entered at the one time. An output file of effective emission coefficients is delivered fully formatted to the ADF12 specification.

Extension of the CXS capabilities to heavier species

- Motivated by the need to cope with heavier receiver ions beyond argon, which may be partially ionized.
- There are two new codes ADAS315 and ADAS316. ADAS315 works on a scaleable universal dataset of format ADF49 to produce an ADF01 data set.
- ADAS316 is a bundle-n population model. It requires a driver data set and, for bundle-n in ADAS, these have historically been archived in ADF25. A new sub-directory /a25_p316 has been assigned and a complete redesign of the driver has been carried out.
- Output ADF26 (the bundle-n population solution), ADF12 (charge exchange effective emission coefficients) and ADF40 (feature emissivity coefficients) may be produced.
- For heavy species CXS, because of the very large number of transitions between highly excited states, the ADF40 format becomes more useful that ADF12.

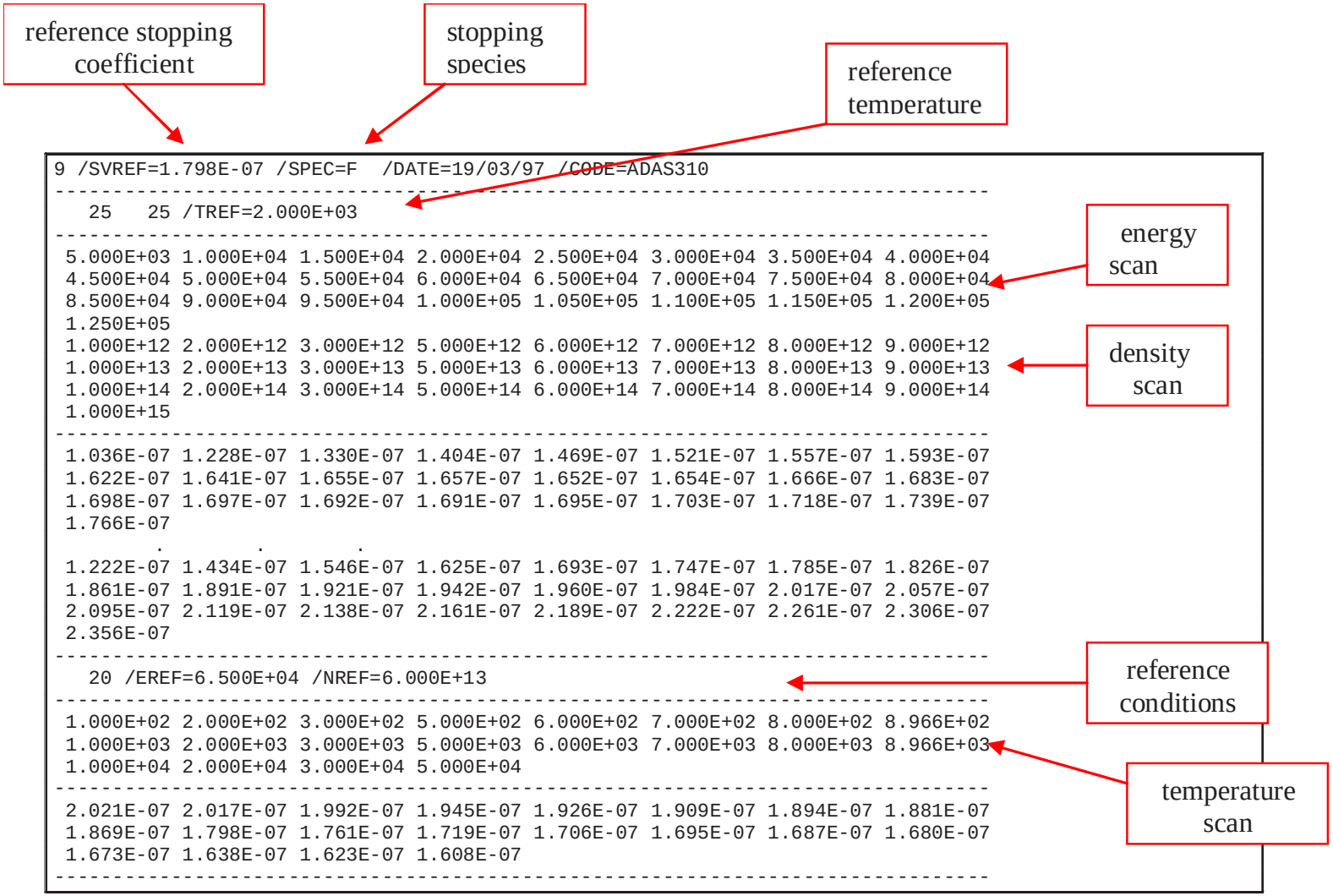
Part II: Beam stopping and beam emission spectroscopy

- Extracting effective beam stopping coefficients or beam emission coefficients using ADAS304.
- Calculating the beam population structure using ADAS310
- Details of beam emission with adas305_get_stark.pro

Interrogating effective beam stopping coefficients

- Datasets of class ADF21 contain effective stopping data as a function of beam and plasma parameters for different plasma species.
- Datasets of class ADF22 contain effective beam emission data as a function of beam and plasma parameters for different plasma species.
- Code ADAS304 interrogates ADF21 or ADF22 data sets to provide coefficients at beam and plasma conditions of your choice.

ADF21 beam stopping coefficients

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 4.500E+04 5.000E+04 5.500E+04 6.000E+04 6.500E+04 7.000E+04 7.500E+04 8.000E+04
 8.500E+04 9.000E+04 9.500E+04 1.000E+05 1.050E+05 1.100E+05 1.150E+05 1.200E+05
 1.250E+05
 1.000E+12 2.000E+12 3.000E+12 5.000E+12 6.000E+12 7.000E+12 8.000E+12 9.000E+12
 1.000E+13 2.000E+13 3.000E+13 5.000E+13 6.000E+13 7.000E+13 8.000E+13 9.000E+13
 1.000E+14 2.000E+14 3.000E+14 5.000E+14 6.000E+14 7.000E+14 8.000E+14 9.000E+14
 1.000E+15
--------------------------------------------------------------------------------
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 2.356E-07
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--------------------------------------------------------------------------------
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 1.000E+03 2.000E+03 3.000E+03 5.000E+03 6.000E+03 7.000E+03 8.000E+03 8.966E+03
 1.000E+04 2.000E+04 3.000E+04 5.000E+04
--------------------------------------------------------------------------------
 2.021E-07 2.017E-07 1.992E-07 1.945E-07 1.926E-07 1.909E-07 1.894E-07 1.881E-07
 1.869E-07 1.798E-07 1.761E-07 1.719E-07 1.706E-07 1.695E-07 1.687E-07 1.680E-07
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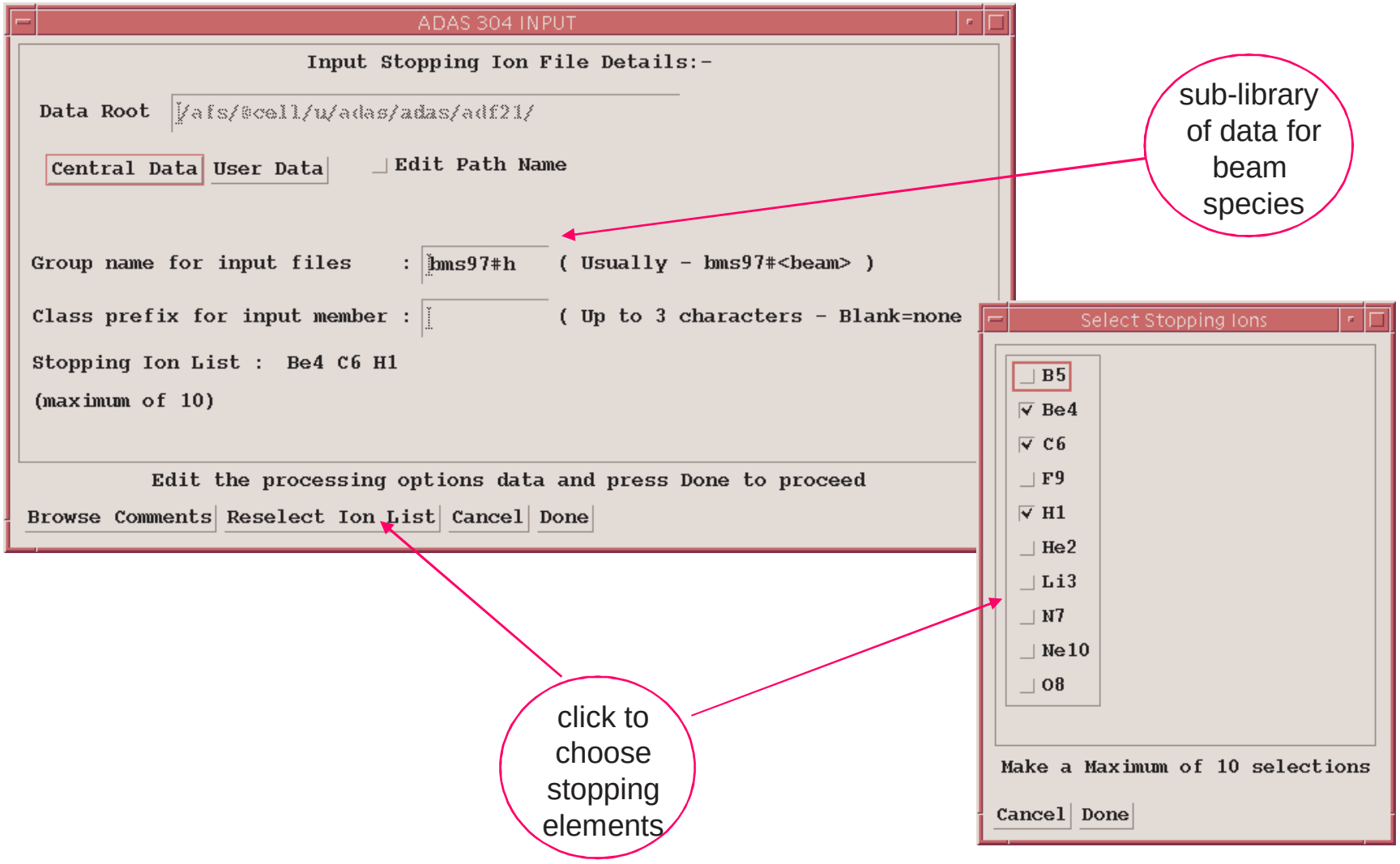
--------------------------------------------------------------------------------
```

ADAS304 Input



ADAS304 Processing

select type of graph display

specify beam and plasma conditions

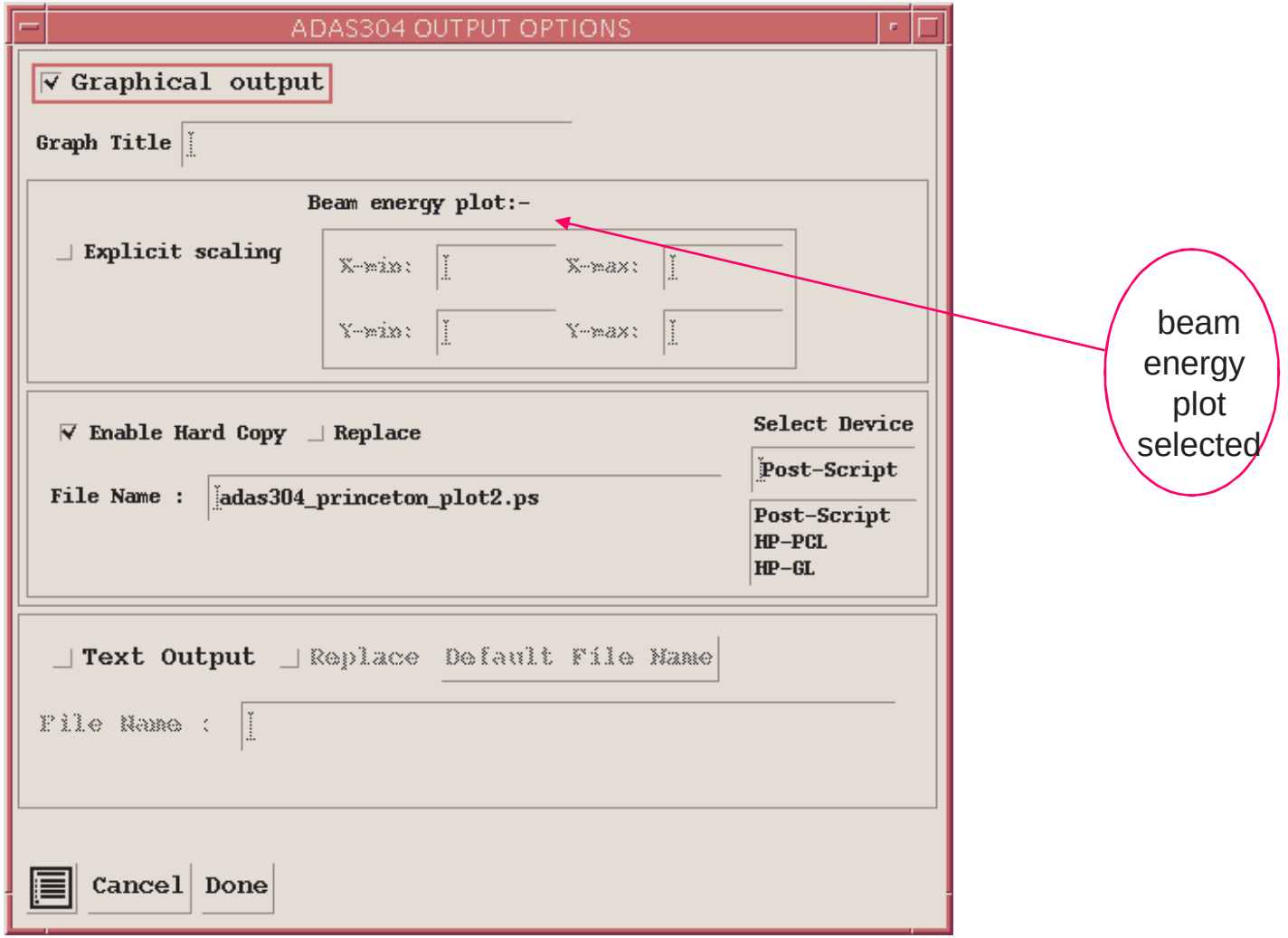
set fractions for each stopping species

Obtaining effective beam stopping or emission coefficients (contd.)

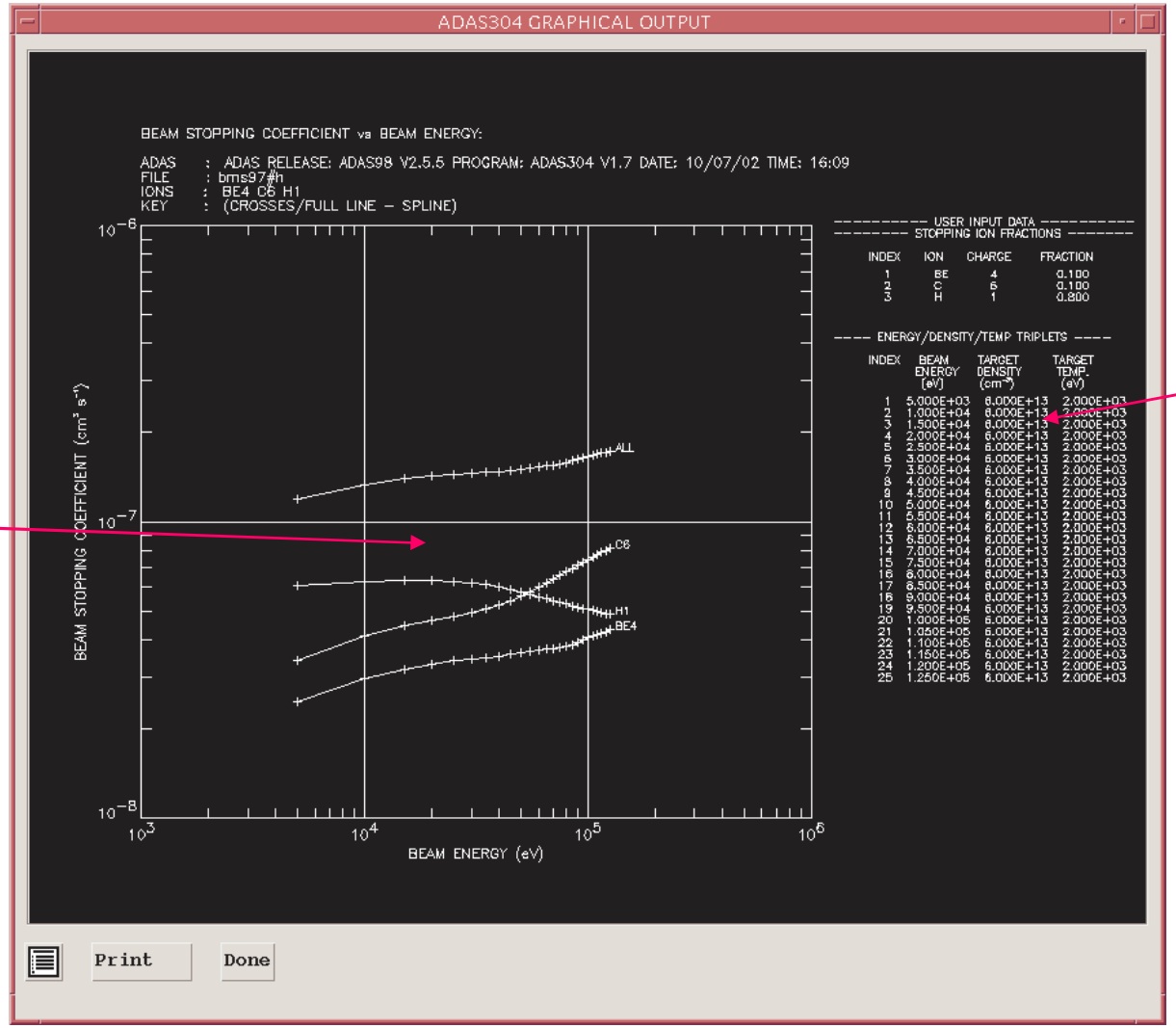
- The composite stopping for a mixed composition plasma is assembled as

$$N_e S_{CR}^{(A)}(E_B, N_I, T_I) \approx \sum_{i=1}^{I} N_{e,i}[S_{CR}^{(i,e)}(E_B, N_I, T_I) + (1/z_{0i}) S_{CR}^{(i,z_0)}(E_B, N_I, T_I)]$$

ADAS304 output



ADAS304 graph



Each contribution to stopping and total

specified conditions

Computing effective beam coefficients

- The first step is the calculation of the full collisional-radiative population structure of the hydrogen beam atoms.
- Code ADAS310 performs these calculations in the bundle-n model.
- It executes these repeatedly for the sets of plasma parameters required to construct tables containing the excited population structure and beam stopping.

Computing effective beam coefficients (contd.)

- The full population structures are archived in ADF26 according to (single) impurity.
- Code ADAS312 post-processes the ADF25 files to extract the beam stooping and beam emission coefficients of choice.
- The output is structured according to the ADF21 (beam stopping) and ADF22 (beam emission) specifications.

Computing effective beam coefficients (contd.)

- File selection
  - » Two input files may be selected.
  - » The first, called the expansion file, gives the pathway for storing condensed collisional-radiative matrices.
  - » The second, charge exchange file, is not important for the beam case. ADAS310 can compute hydrogen populations in the plasma (including CX) as well as beams

ADAS310 Input

beam species

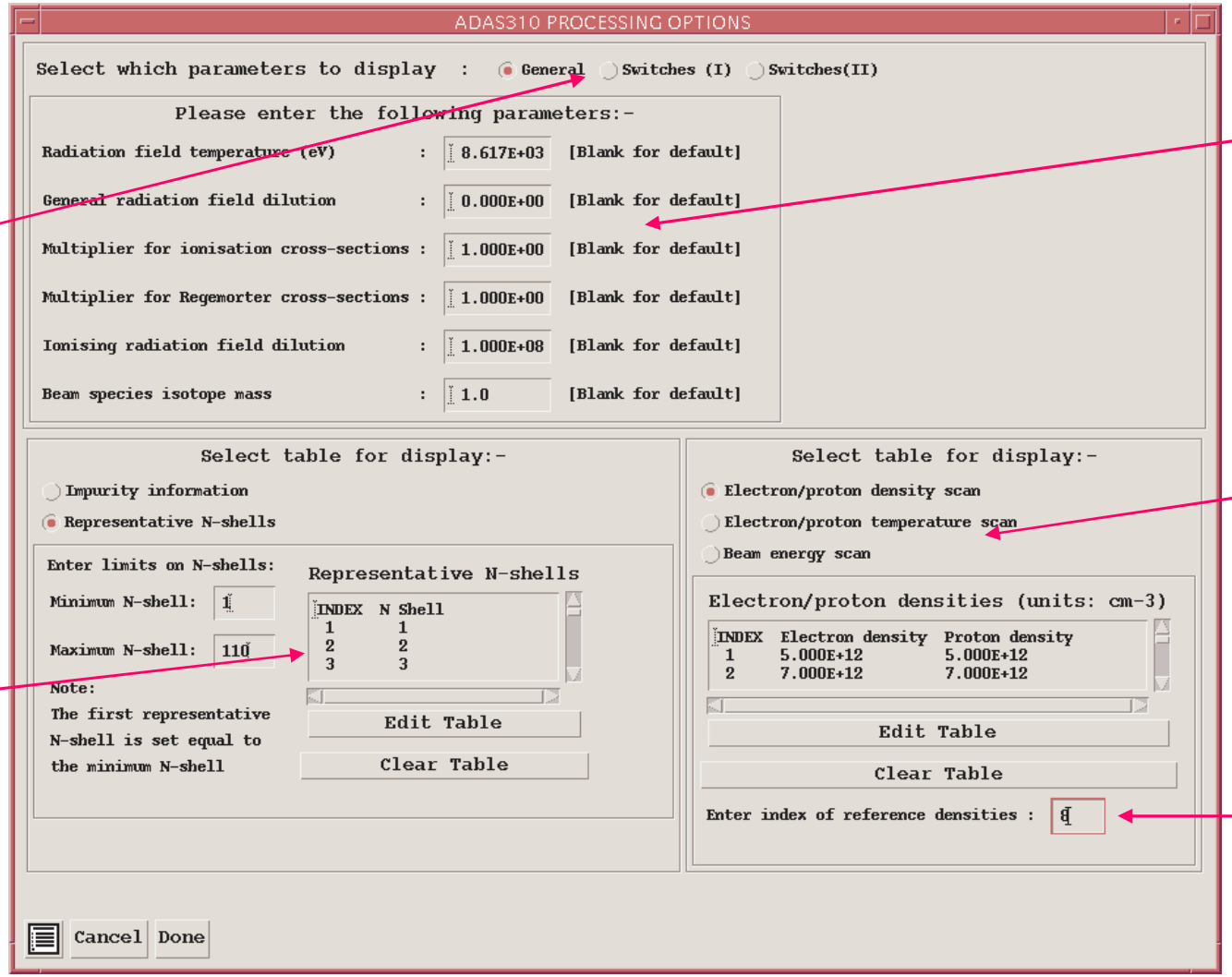
expansion file for high n-shell handling

advanced usage not applicable to simple stopping

Computing effective beam coefficients (contd.)

- Processing options
  - » There are many parameters to specify but most are set with defaults.
  - » The main user data are the impurity specifications and the plasma parameter scans.
  - » ADAS310 can work with mixed impurities but main tabulations are for single impurities which are linearly combined for mixtures at the spectral analysis stage

ADAS310 Processing



three sets of switches - defaults are set

general parameters controlling x-sect. use

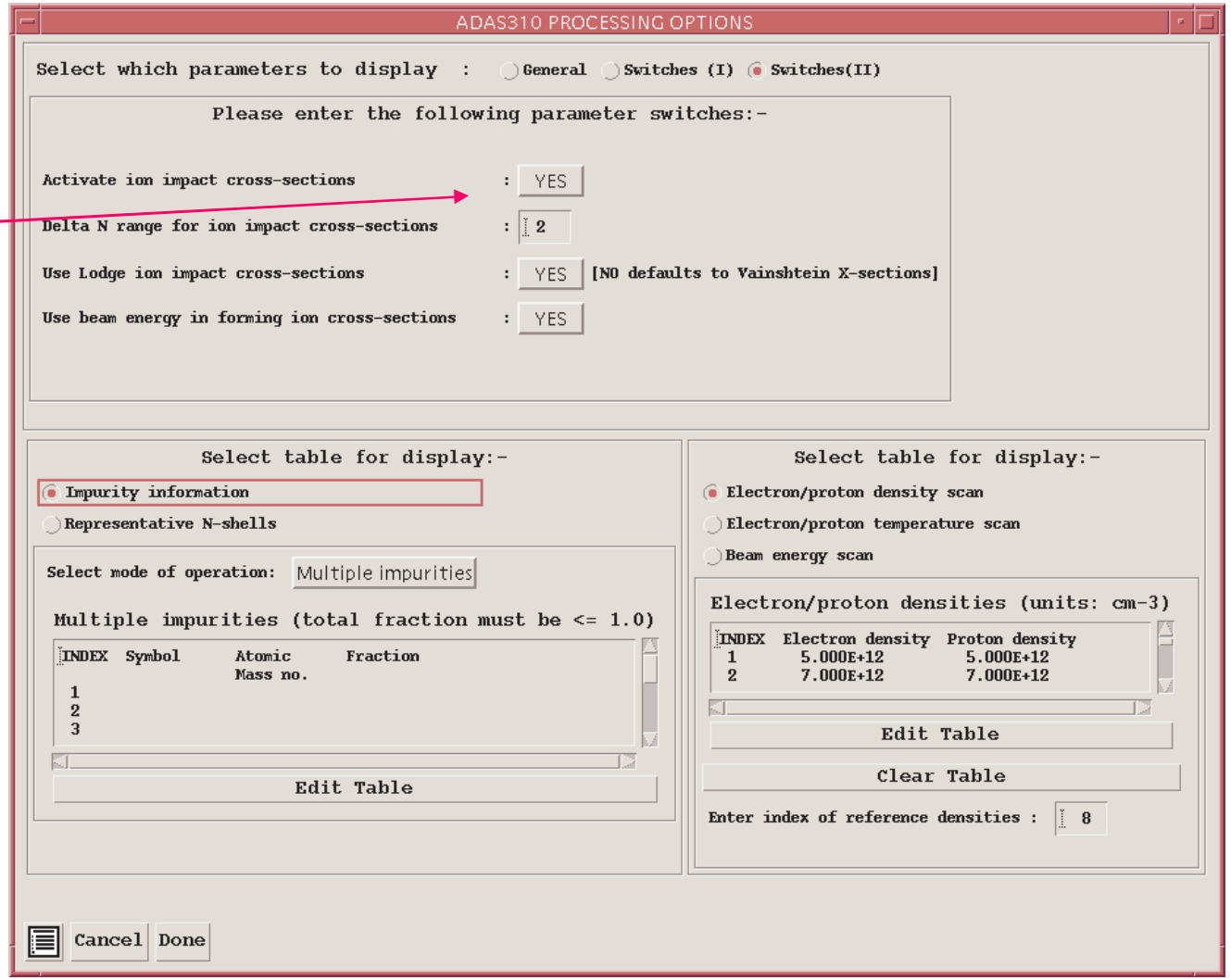
specify scans in key parameters

specify details of bundle-n model for hydrogen

note use of reference conditions

ADAS310 Processing (contd.)

third switch set



Computing effective beam coefficients (contd.)

- Output options
  - » There is no graphical display from ADAS310.
  - » Several pass files are created
  - » The fourth passing file is the population structure (ADF26)
  - » Execution time is longer than most interactive codes.

ADAS310 Output

extended set of passing files for post-processing

Beam emission and the Balmer alpha Stark multiplet structure

- The calculation of local Stark/Zeeman emission feature from H (D/T) beams is accessed via an IDL procedure call *adas305_get_stark.pro* or within FORTRAN by calling the *stark.for* routine in the adas3xx library.

- The beam, plasma, E and B fields and observation orientation must be specified. General geometry specification is defined by direction cosines. The polarisation can be specified by multipliers on the π and σ components.

- The feature is returned as either a collection of component wavelengths and emissivities or a Doppler broadened feature over a specified wavelength range (specify minimum and maximum wavelengths and number of pixels).

adas305_get_stark.pro

```
PRO stark_fig

beam   = {mass : 2.0, energy : 40.0e3, te : 10.0, density : 4.27e9, $
          dc_x : 0.0, dc_y : 0.0, dc_z : 1.0}
plasma = {mass : 2.0, te : 8e3, density : 5.0e13, zeff : 2.0}
bfield = {value : 3.3915, dc_x : 0.788, dc_y : 0.0053, dc_z : 0.6152}
efield = {value : 0.0000, dc_x : 1.000, dc_y : 0.0000, dc_z : 0.0000}
obs    = {dc_x : 0.8701, dc_y : -0.047, dc_z : 0.4905, sigma : 0.00, pi : 1.0}

wave_min = 6510
wave_max = 6550
npix     = 500

adas305_get_stark,  beam           = beam,          $
                    plasma         = plasma,        $
                    bfield         = bfield,        $
                    efield         = efield,        $
                    obs            = obs,           $
                    n_lower        = 2,             $
                    n_upper        = 3,             $
                    wave_comp      = wave_comp,     $
                    emiss_comp     = emiss_comp,    $
                    wave_min       = wave_min,      $
                    wave_max       = wave_max,      $
                    npix           = npix,          $
                    emiss_doppler  = demiss   , /doppler  ; , /nocheck

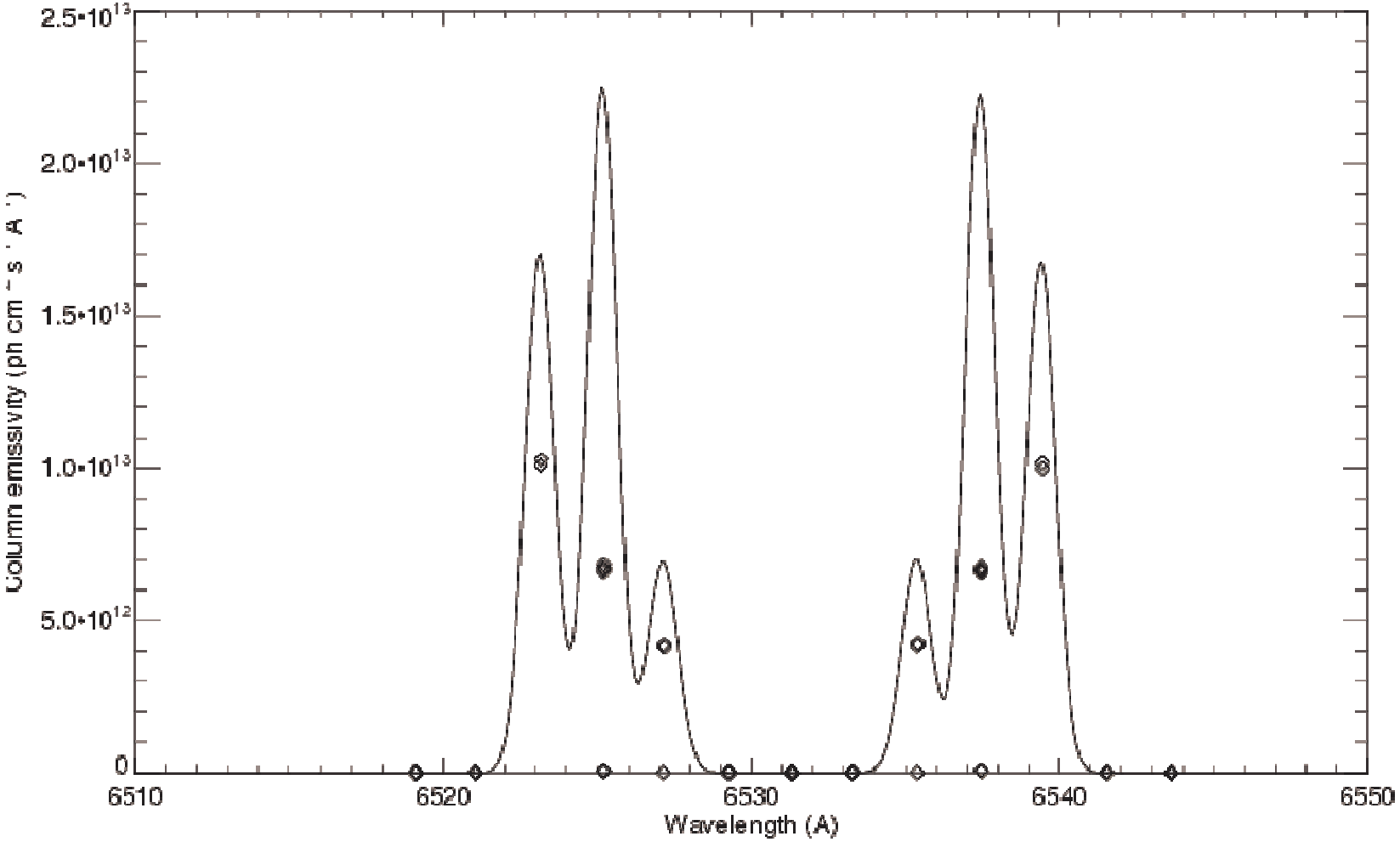
wave  = adas_vector(low=wave_min,high=wave_max,num=npix, /linear)
dwave = wave[1]-wave[0]

plot, wave, demiss/dwave, $
      xtitle = 'Wavelength (A)', $
      ytitle = 'Column emissivity (ph cm!u-2!n s!u-1!n A!u-1!n)'

plots, wave_comp, emiss_comp, psym=4

END
```

Balmer alpha Stark multiplet



Feature variation

B: 1.4T – 50 T

E: 0.5Mev/amu – 100eV/amu