

- Script Updated: October 2017

## 1 Data Analysis procedures

In this part of the laboratory you have the opportunity to extend your curve fitting skills, investigate the need for instrument response corrections and data interpolation. This laboratory focuses on SSC streak camera data.

### b) SSC data

With SSC data it is possible to estimate electron density and temperature of the imploding core with time. To do this it is necessary analyse an emission spectrum and compare this to some model. In this laboratory you have the opportunity to analyse one spectrum extracted from SSC data. As your analysis proceeds you will need to i) apply a number of wavelength dependent corrections, ii) fit a baseline to remove the background and then iii) find the line width in the Ly- $\beta$  and He- $\beta$  transitions. From the line widths you can estimate electron density at one point in time. By repeating this process you could build up a graph of  $n_e$  time, but for this lab we will start by focussing on a single time, close to peak compression.

#### 1. *Extracting a spectrum:* Using ImageJ to extract the intensity spectrum

- Load the SSC data image into ImageJ.
- As the image is digitised with a resolution that exceeds the instrument resolution (i.e. oversampled to ensure data is not lost in the digitisation process), we can average over a number of a pixels when taking a cross-section. This reduces the digitisation noise. The number of pixels depends on your analysis of the instrument resolution. It is possible to estimate the streak camera temporal resolution  $\Delta\tau$  from the sweep-speed  $v$ , the width  $d$  of the slit in front of the photocathode, instrument magnification  $M$  and spatial resolution  $\Delta s$ . The produce  $dM$  and  $\Delta s$  need adding in quadrature to give

$$\Delta\tau \sim \frac{\sqrt{(dM)^2 + (\Delta s)^2}}{v} \quad (1)$$

Use this information to choose and justify a suitable lineout width.

- Take a cross-section through the Ar K-shell emission and save the data as a text file again. Choose a time when the spectrum is bright similar to that shown in Figure 1.
- It is important to note all steps in your lab books to enable a repeat of your analysis at any time.

#### 2. *Fitting a dispersion:*

- Import the data into Python as done in the GXI analysis. Note, you will end to use a number of data arrays, and so you should name them sensibly to enable easy identification.
- Plot a graph of your initial cross-section to check that it matches the one in ImageJ. At this point you should identify the peaks in the spectrum based on their approximate positions. See table 2 in the prereading script to find the expected lines. You should use the Python plot window to find the position of each peak by hovering the cursor over it and noting the x coordinate. This should give you a rough calibration of x-ray energy vs pixel across your lineout.
- Crop your data as illustrated in Figure 2, just as you did for the GXI data in the previous script. Be sure that your peaks remain at the same pixel number after cropping, otherwise your calibration from the previous step may be affected.

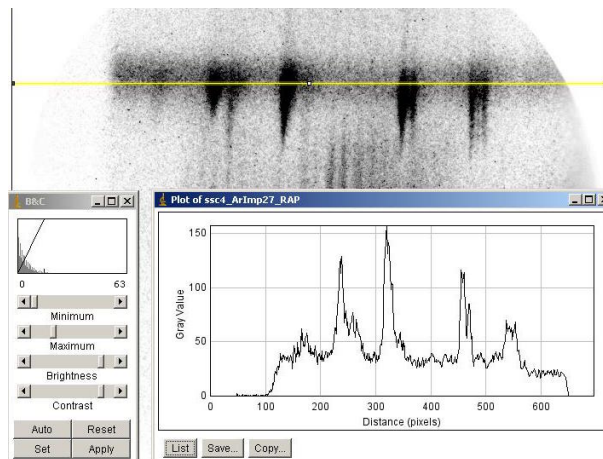


Figure 1: The SSC data in ImageJ showing a suitable position for a cross-section for analysis. In Python the data will be windowed between Distance (pixels) 135 and 625.

- (d) Make two new arrays containing the pixel numbers (called *peakCentre*) and energies (called *peakEnergy*) associated with each peak, as determined in the previous section. These should be of the same length.
  - (e) Plot the *peakEnergy* array against *peakCentre* to give a dispersion curve. Read the next few steps, and think carefully about which to use as the x-axis, and which the y. Fit a low order polynomial (say a line, quadratic or cubic) to this graph. You will need to be careful at this point a poor fit here will affect your calibration.
  - (f) Use your fit to generate a new x array which replaces pixel number with energy. You should now be able to plot a your spectrum with the x-axis as energy. Do so, and carefully check that your calibration has placed all your peaks at the correct positions.
3. *Instrument corrections*: Although we now have an energy calibration, there are various energy dependent effects which will have distorted the intensities recorded on the detector. This information is extracted from published work. To apply these we need to know the value of the correction at the energies at which we have sampled our data. However, in general, the correction data we look up will be supplied at different points to those we want. To evaluate the corrections at the correct energies we will interpolate the correction data. There are three corrections for you to apply.
- (a) *Filter attenuation*: Use the CXRO site ([http://henke.lbl.gov/optical\\_constants/filter2.html](http://henke.lbl.gov/optical_constants/filter2.html)) to estimate x-ray attenuation due to filtering (see Part 1 for details) as function of wavelength (or energy),  $T(E)$ . CXRO will plot a graph by default. You can download the data (in a format you can read into Python) by clicking 'data file here' at the top of the window.
  - (b) *Crystal reflectivity*: A file is provided on the MSc website containing this correction. The data comes from reference [1] which provides estimates the crystal mosaic integrated reflectivity  $R_m(\text{mr})$  as a function of wavelength (or energy),  $R(E)$ .
  - (c) *Photocathode sensitivity*: A file is provided on the MSc website containing this correction. The data comes from reference [2] which provides estimates of the photocathode response as a function of wavelength (or energy),  $C(E)$ .

For each correction, you need to interpolate the data onto the same x points as you are using for your cropped spectrum. See the example file 'interpolate.py' to see how this is done in Python. Once this is done you should have the following five arrays available in python –

- (a) An x-axis containing the energy points for your data.
- (b) A y-axis containing the uncorrected spectrum data.
- (c) Three more y-axes containing the  $T(E)$ ,  $R(E)$  and  $C(E)$  corrections for the same energy points as your spectrum.

As always, you must keep a complete record of all steps in your lab book.

#### 4. The corrected spectrum

- (a) Once interpolated, the correction waves can be used to produce a final, corrected relative (not absolute) intensity spectrum by using the following formula:

$$I_{corrected}(\lambda) = \frac{I_{measured}(\lambda)}{T(\lambda)R(\lambda)C(\lambda)} \quad (2)$$

- (b) Display the original and corrected data - the changes across the spectrum should be relatively modest (This is a sign of a well designed experiment).

#### 5. Fitting the Ly- $\beta$ and He- $\beta$ lines

- (a) We will only be interested in the Ly- $\beta$  and He- $\beta$  transitions for our analysis, so you can start by cropping your data to only include this area of the spectrum. Be sure to crop within a flat region of the spectrum to ensure accurate fitting.
- (b) Next, you will need to fit Gaussians to the peaks. Once again, you can use our fitting routine, but you will now need numerous Gaussians, rather than just one. To do this, expand your Gaussian function to return the sum of the required number of individual Gaussians, and as before, increase the number of parameters passed to the function, and the number of initial guesses in the array.
- (c) Your aim is to get a good fit to the selected region of the spectrum. You may find that in order to do this you need to fix some parameters (such as the central position) of some of your Gaussians to aid the fitting routine. You can either hard code this into your fitting function, or you can take a look at a more sophisticated method in the example file 'fix\_parameter\_fit.py'.

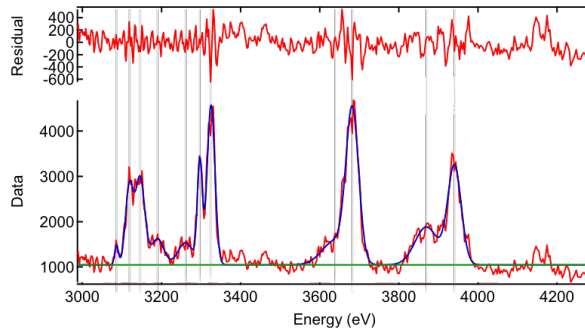


Figure 2: A example of a multipeak fit to a corrected spectrum.

- (d) At this point you should have fits to both the Ly- $\beta$  and He- $\beta$  peaks, as well as any neighbouring lines. Both lines of interest should have a similar width. It is possible (likely) that this is not the case, the reason is that there are two close lying peaks in the He- $\alpha$  transition whereas your fit is treating this as one peak. If this is the case you may need to manually add an additional peak with fixed parameters. The He- $\alpha$  is on the high-energy side the of two.

#### 6. Instrument resolution: Accounting for spatial-spectral resolution

- (a) Your instrument (which is a combination of spectrometer, filters, streak camera, film, and digitiser) modifies the signal entering an instrument in a number of ways. For example your spectral measurements,  $M$ , are convolutions of the signal,  $S$ , detected by the instrument and instrument spectral resolution,  $R$ .

$$M = S \otimes R \quad (3)$$

Before comparing measurement with theory it is essential to estimate  $R$  and remove this from your measurement. This correction is straight forward if  $M$ ,  $S$  and  $R$  are well described by Gaussian functions as the affects add in quadrature. Retrieving the signal FWHM then follows

$$S_{FWHM} = \sqrt{M_{FWHM}^2 - R_{FWHM}^2} \quad (4)$$

source size	100 $\mu\text{m}$
spectrometer	0
filters	0
SSC spatial resolution, $\Delta s$	150 $\mu\text{m}$
film	1 $\mu\text{m}$
digitisation	60 $\mu\text{m}$

Table 1: Suggested parameters for estimating the instrument response function of the SSC and spectrometer. As the spectrometer was slitless, the source size is potentially an important parameter. If a source becomes too large then it is essential to use a slit.

- (b) The next step is to estimate  $R$  from information provided and then correct your analysis to give  $S_{FWHM}$  and calculate integrated intensities. A good place to start is with guess-estimates of add these is quadrature, then using your dispersion ( $\text{\AA}/\mu\text{m}$  or  $\text{eV}/\mu\text{m}$ ) estimate how much the instrument as a whole broadens a spectral line. This is  $R_{FWHM}$ .

## Writing up

By the end of this week you should have good quality fits to the data, allowing you to calculate the widths and integrated areas of the Ly- $\beta$  and He- $\beta$  peaks.

Your laboratory notebook should contain details of all the analysis undertaken. This includes recording estimates, stating what images were used, the position of the cross-sections, width of the cross-sections, the parameters used for cross-section reduction etc. You should include appropriate images of the steps taken. In short, your laboratory notebook must contain a record of all the important experimental details to enable a reproduction of analysis.

Your final result should include FWHM estimates for the signal  $S$  with associated errors. This is your opportunity to discuss parts of your analysis that requires further investigation (if you had the time). List these and clearly identify the problems or issues.

## References

- [1] BL Henke, EM Gullikson, JC Davis, Atomic Data and Nuclear Tables, 54, 181-342 (1993)
- [2] K. Premaratne, E. R. Dietz, and B. L. Henke, Nucl. Instrum. Methods Phys. Res. 207, 467 (1983); B. L. Henke, J. P. Knauer, and K. Premaratne, J. Appl. Phys. 52, 1509 (1981); B. L. Henke, in Low Energy X-Ray Diagnostics, edited by David T. Attwood and Burton L. Henke, AIP Conf. Proc. 75 (AIP, New York, 1981), p. 146.