## Chapter 7: Result of Spectroscopic Profiles

### 7.1 Profile Calculation

A profile for and by spectroscopic measurements is only possible over the ~35cm viewing range of the viewport. Each measurement consisted of one shot on the Helimak, with several integrations averaged and processed as described in chapter 3. Spectroscopic measurements were taken at 1cm increments for a total of 34 different positions.

The methods in chapter 4 were used to determine a value of and at each position, including the correction factors calculated in chapter 6. Initially, a flat density profile was used for neutral Argon, and equal to the pressure recorded from the ionization gauge. In this case the measured total density before the shots was , and . The resulting profiles are shown in figure 7.1.

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Figure 7.1 and using the spectroscopic measurements and a flat neutral profile.

The values of and were then used with the kinetic model developed in chapter 5 to give a density profile for the neutral Argon. For the first iteration, a fitting parameters for of and were used in eq. 5.25. The new neutral profile was then used to calculate new values of and . This process was repeated several times until the resulting , , and were the most self-consistent.

The coefficient of determination, , was used as the quantitative measure for which profile best fit the measured spectroscopic data. Here , , are the measured values of or , and is the fitting function used in the kinetic model. The only parameters varied were the peak or used in the fitting function, or the parameter in eq. 5.25.

Figure 7.2a gives the values of for different computed profiles as a function of . is also varied for each profile, but not independently of . The best fit appears to occur when the fitting parameter . However, the fitting for is much worse than , which may indicate that the fitting function used is not quite adequate.

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| (a) | (b) |

Figure 7.2 (a) between fit used in kinetic model, and resulting and profile. (b) Ar I profiles computed using kinetic model.

Figure 7.2b shows the profiles for Ar I at the fitting values of and . For the best profile is for fitting , the calculated neutral profile shows a z-average depression of the Ar I density in the center of the Helimak of about 10-15%. This is in addition to the ~8% total depletion compared to .

The resulting best fit spectroscopic profiles for and are shown in figure 7.3 As can be seen, the fitting function for also does not quite match the trend in the density, which appears to peak at a slightly larger radius. The spectroscopic data does not extend far enough to make a good guess for a different fitting function, but it may also be an artifact of some failing of the Ar I kinetic model profile.

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Figure 7.3 Best fit to and using the spectroscopic measurements and neutral profiles in figure 7.2. Gives peak of about 10eV, and for .

In figure 7.4, the profile determined by the spectroscopic method is compared to that obtained by probes from a shot of the same parameters. Probe data was provided by K. Gentle. Error bars for the spectroscopically determined values come from the possible systematic error of calibration and atomic data only, and does not include error introduced by poor fitting from the kinetic model. The values of , peaking around 10eV, agree roughly with probe measurements. The profile is more striking since the values do not agree, and are higher in magnitude than the probe measurements. The average of the ratio of the two measurements is , with the error estimated as .

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Figure 7.4 Best fit to and , with error bars, using the spectroscopic measurements, compared to probe measurements provided by Dr, K. Gentle from a shot with same control parameters.

### 7.2 Electron Density Limit

Since the electron density found by the spectroscopic method appears to be much higher than from probe measurements, there should be some sanity check to make sure a higher value is reasonable. There are several absolute limits placed on the electron density. One is the cutoff frequency of the plasma, which would reflect RF power from the plasma and prevent it from heating. For an RF frequency of 2.45GHz, the critical , which is still above the measured value.

The other limit on the electron density is the total input RF power, which for this series of shots is 6kW. The major power loss mechanisms are the ionization of neutrals, line emission radiation, and the thermal energy through lost particles exiting the plasma. Luckily, a byproduct of the kinetic model of chapter 5 is that it computes the total ionizations per second within the Helimak, which gives the total ionization power by multiplying by the ionization energy. Thermal losses are estimated by again using the total ionization rate to define an effective confinement time of the ions. Total line emission radiation power is calculated using data from Fournier et al.[14].

The average ionization rate computed from the kinetic model at the 8.3eV level was . Multiplying by the neutral density and volume of the plasma gives the total ionizations per second. With , and , this gives . With an ArI ionization energy of 15.8eV, this would give a total ionization power of 1.24kW.

The thermal power loss can be defined by summing the total rate of ion loss at each radius times the average thermal energy per electron, since the ions are assumed to be cold. Using the fitting functions and the solution to the neutral profile, at each radius this gives a power loss of . Summing over all radii gives total thermal power of .

Finally, the line radiation power density was taken from ref. [14], which gives the radiative cooling per neutral density, per electron density as a function of temperature. It is given by fitting function eq. 7.1, and the fitting coefficients were used for the range of 2-20eV and are replicated in table 7.1. Summing over all radii gives a total radiative power of 2.5kW.

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|  | Fitting Parameter |
|  | -3.7573E-20 |
|  | 2.8398E-17 |
|  | -7.4088E-15 |
|  | 2.2873E-12 |
|  | -1.3614E-10 |
|  | 2.4647E-9 |

Table 7.1 Radiative cooling rate of Ar I fitting parameters for in the range of 2-20eV from Fournier et al.[14]

Summing the power loss from ionization, radiative cooling, and thermal losses gives a total power loss of about 4.6kW, which is ~76% of the total input power. This means that it appears possible for the electron density to be this high from a power balance perspective. If they above calculations were scaled down by 2.2x to match the probe , then it would only account for ~35% of the input power. While the ECRH would not be expected to couple 100% of the RF power, this seems like a low end for an expected heating efficiency.

### 7.3 Possible High-Low pass filtering method

The procedure in chapter 3 requires two rather long integration times per measurement to capture both the stronger and weaker lines due to the saturation of the spectrometer’s detector and noise level. It also requires processing of each line of the spectrum individually. However, all of the Ar I lines used lie in the range of 690-970nm, and all of the Ar II lines used lie in the range of 430-490nm, which leaves a ~200nm gap between the two sets of lines.

Since all of the Ar I lines end up grouped together anyway, it should be possible to simply sum over all lines in that range and find a relation between the total emission in that range, and the compound excited state density of each ion.

This would allow the use of a simple filter lens to split the light from the plasma into the two wavelength ranges, which could then be detected by a photodiode, or even a ccd camera, at a much higher sampling rate. The filter method could be calibrated against the spectroscopic method, and, with some assumptions about the neutral density, then be used as a redundant measurement for and .

As an example calculation, an Edmund Optics Dichroic Longpass Filter NT69-867 could be used with a reflection range of 415-515nm (low pass), and transmission range of 575-1600nm (high pass). Using the spectroscopic profile data, the correlation between the low/high pass integrals over those wavelength ranges and the calculated compound states are show in figure 7.4.

In this simple example, the calibration factor would be for the low pass integral to , and for the high pass to . Again, errors are given by . The values of the compound excited state density could be found by . This calculation would only demonstrates the feasibility of this method. In practice the new optical system would be calibrated using some known source.

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Figure 7.4 Correlations between a high/low pass filter, and intensive calculation of excited state densities.

Using a fast CCD camera with the splitting optics, such a system might also be capable of imaging and of the entire plasma at once, capturing any time-dependent spatial irregularities.

### 7.4 Conclusion

Using spectroscopic measurements of neutral Argon has proven to be very tricky due to its high ionization cross section, and resulting depletion within the plasma. The fitting functions used in chapter 5 may be insufficient since the resulting profile for appears to have a different shape. The neutral profiles are also sensitive to the source (recombination) profile used, which is not really known. The breaking of the axial and vertical symmetries due to the termination of the plasma on the bias plates may also require a more sophisticated kinetic model.

Even though the shape of the electron density may be incorrect, it does seem to indicate a peak electron density 2.2x higher than probe measurements, which still seems possible from a power balance perspective. This difference may be responsible for the large discrepancy previously observed which lead to this work, since a smaller increase in would require a larger decrease in given the same spectroscopic measurement, resulting in an exaggerated observed neutral depletion.

There may also be future possible extensions of this work that could obtain and profile on a per-shot, or many times per shot, basis. This would be a larger improvement since the current method requires many identical shots to build up a profile, with several integrations per shot.