Bulk electron temperature measurements using Asymmetric Triple Langmuir probes

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Langmuir probes are often used to obtain measurements of temperature and density in plasma. Many believe that the standard triple probe does not give a correct measurement of temperature since it samples only the fastest electrons, and that another type of probe needs to be designed that would sample more dominant, bulk, electrons in the plasma. My project this summer has been to make an asymmetric triple probe that would allow for the bulk measurements of temperature in the plasma and to test it in comparison to the standard triple probe. It also involved checking for the existence of drift waves in the gradient regions of plasma and testing probes' sensitivity to temperature fluctuations.

1 Introduction

Langmuir probe is one of the simplest probes used, composed of a long shaft with one tip at the end of the shaft. It is biased by an outside voltage (applied with respect to the ground). In order to obtain a temperature measurement, its current-voltage characteristics need to be swept (Figure 1). As probe is negatively biased, it tends to collect more ions and repel electrons, eventually reaching its ion current saturation level. If biased positively, it starts collecting electrons and repelling ions, reaching its electron current saturation level. Voltage 3 on the diagram is the floating potential voltage at which the probe collects the same amount of ions and electrons, and thus the overall current through the probe is zero. The problem with this probe, however, is that it cannot resolve fluctuations, so it cannot be used for the study of waves in a plasma. The standard triple Langmuir probe is superior to the standard Langmuir probe because it gives instantaneous measurements of temperature (thus no sweeping is required) and it can be used to resolve fluctuations.

The standard triple probe (Figure 2) works as follows. It is inserted in the plasma, and by measuring voltage drop across 330 ohm resistor, ion saturation current is determined. Electrons are collected by the electron collecting tip so that the current loop going through the ion and electron tips is closed. The third tip inserted into plasma and connected to the large impedance (about 1 Mohm) is floating potential tip, and it does not draw any current. Floating potential serves as a reference voltage for the other measurements in plasma. Moreover, the difference between the electron collecting tip potential and the floating potential is a measurement of temperature in the plasma, as shown by the relation $kT_e = \frac{e(V_e - V_f)}{ln(1+\frac{A_i}{A_e})}$ where 'i' refers to the ion tip and subscript 'e' to the electron tip and V_f stands for the floating potential. Since ions are a heavier and slower than electrons, they determine the rate at which electrons are collected and the type of the collected electrons.

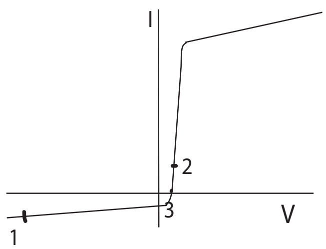

Figure 1: Current-Voltage curve of the standard Langmuir probe

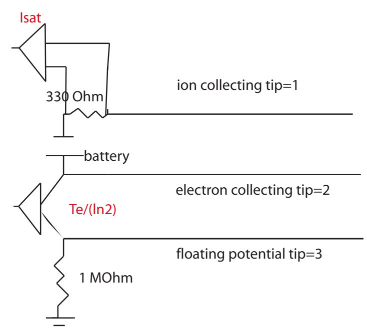

Figure 2: Schematics for the standard triple probe

For the symmetric triple probes (where the area of the ion collecting tip is the same as the area of the electron collecting tip) I-V curve looks the same as for the standard Langmuir probe (Figure 1). The potential difference between the electron collecting tip and the floating potential is small, thus possibly causing an imprecise reading of temperature. Moreover, the majority of electrons collected by the electron tip are the fastest electrons (or tail electrons of Maxwellian distribution) which characteristic is higher temperature. The reason why tail electrons might not accurately represent the temperature of Maxwellian distribution is that they are easily affected by the primary electrons and waves in the plasma. Moreover, primary electrons are electrons that do not get collected by the anode and get into the plasma, possibly thermalizing to a hot tail and thus destroying Maxwellian distribution. There is also a concern about wave-particle interactions where energy of the electrons might change due to the wave and lead to the creation of a beam tail, once again destroying Maxwellian distribution. Hence, assuming Maxwellian distribution of plasma for temperature measurements in such cases would lead to an incorrect value of temperature. A possible solution to this problem is creation of an asymmetric triple probe.

2 Structure and Function of the Asymmetric Triple Probe

The major difference between the asymmetric and standard triple probe is that asymmetric triple probe has an ion tip that is 6.17 times greater in the area than the other two tips (electron collecting and floating potential tip, Figure 3). An increase in the area of the ion collecting tip leads to collection of more ions out of the plasma, which in turn increases the number of electrons drawn out of the plasma. Furthermore, the number of drawn electrons per unit area of the electron tip increases, and shifts electron potential as well as electron current on the current-voltage curve (Figure 4).

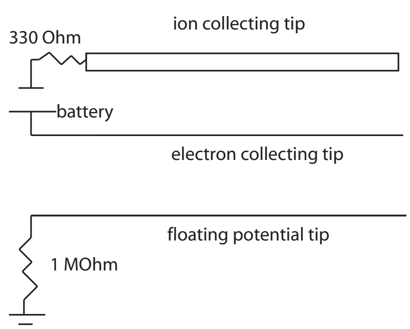

Figure 3: Schematics for the asymmetric triple probe

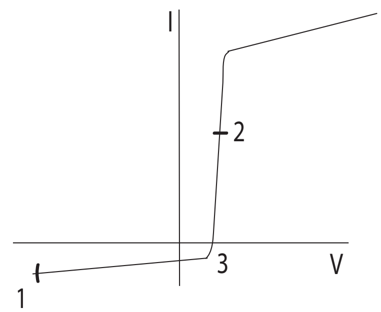

Figure 4: I-V curve of the asymmetric triple probe

With the asymmetric triple probe, floating potential also increases, thus shifting the curve to the right. The three tips lead to the same kinds of measurements as before, but this time by sampling more bulk electrons of Maxwellian distribution.

We have also created an effect of asymmetric triple probe without making any of the tips physically bigger. Moreover, as shown on Figure 5, we have attached current-sink circuit between the ion collecting tip and electron collecting tip. Current sink is consisted of two identical transistors, with the same voltage drop across base-emitter diodes. What this indicates is that voltage drop across 10KOhm and 1KOhm resistors has to be the same. Ion saturation current flows through the collector of the transistor on the left, and most of it continues to flow through the emitter towards the electron collecting tip. Only a small fraction of this current flows into the base of the transistors. As majority of the ion saturation current flows though the 10KOhm resistor, it causes 10 times greater current to flow through 1 KOhm resistor, and in turn electron collecting tip starts collecting about 10-11 times greater current than the ion saturation current. This way collection of electrons per unit area of the electron tip has increased, without physically making ion tip bigger. In order to maintain proper operation of this circuit, anode voltage needs to be above the base voltage (so that both transistors are in active region at all times). No data has yet been collected with this circuit and it will not be further discussed in this paper.

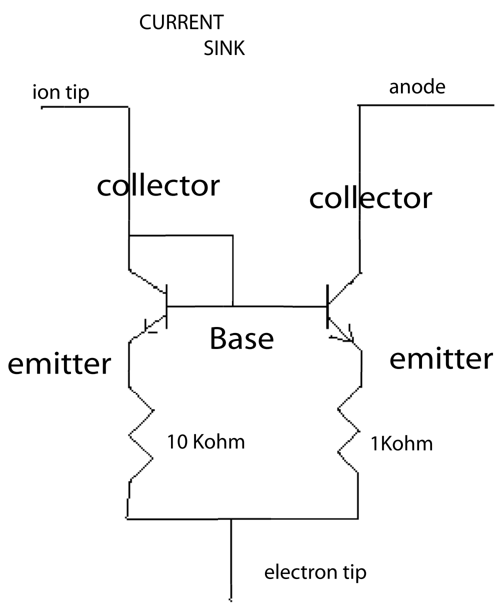

Figure 5: Current Sink

3 Procedure

All measurements of temperature were taken in UCLA's LAPD machine. To obtain comparison in the measurements of two probes, we obtained the data for both probes through 101 positions in the plasma with 10 shot average (for the DC measurements), as well as 1 shot average with 20 shots per position for 57 positions (for RMS measurements that could indicate existence of gradients), and 500 shots total with 1 shot to average at one position (x=0cm, for the power spectrum of temperature). The probes were pumped down to vacuum, inserted into the chamber, and their outputs were connected to the amplifier with 10 times attenuation. Moreover, V_f output was attenuated by another 6dB, as a precaution to prevent reaching saturation level of the digitizer, where the data is stored. In order to look at the fluctuations, a copper structure was inserted inside of the chamber, and current was pulsed through it for a duration of 2ms. All data has been analyzed using IDL.

4 Measurements and Results

The average plasma temperature measurement in LAPD machine is known to be about 5eV (through the swept measurements).

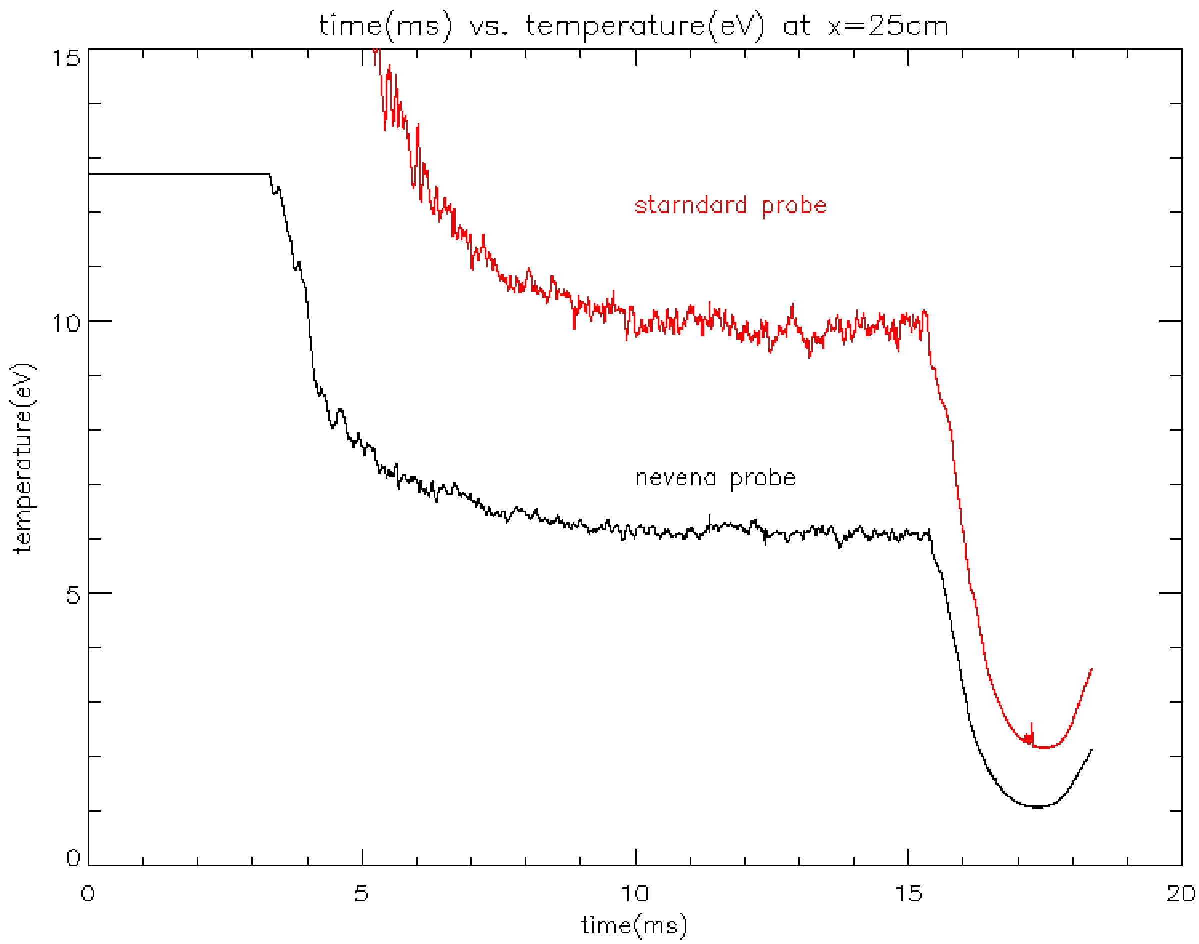

Figure 6: DC Temperature, 'nevena' probe refers to the asymmetric triple probe

Using the asymmetric triple probe, we have determined that the average temperature is about 6eV (Figure 6), while standard triple probe seems to show a measurement of about 10eV. This clearly indicates the possibility that standard triple probe is in fact sampling tail electrons that are hotter than the rest of the plasma, and hence does not lead to the correct measurement of temperature. This is also a confirmation that asymmetric probe samples bulk electrons that do unravel the correct temperature of plasma, and as such is more reliable for the average T_e measurements. However, it is still sensitive to the existence of primary electrons during the first couple of milliseconds after cathode discharges.

Since we are also interested in looking at fluctuations, and comparing sensitivity of both probes to the temperature fluctuations, we took some data while the current was pulsed through the copper structure. As Figure 7 shows, even

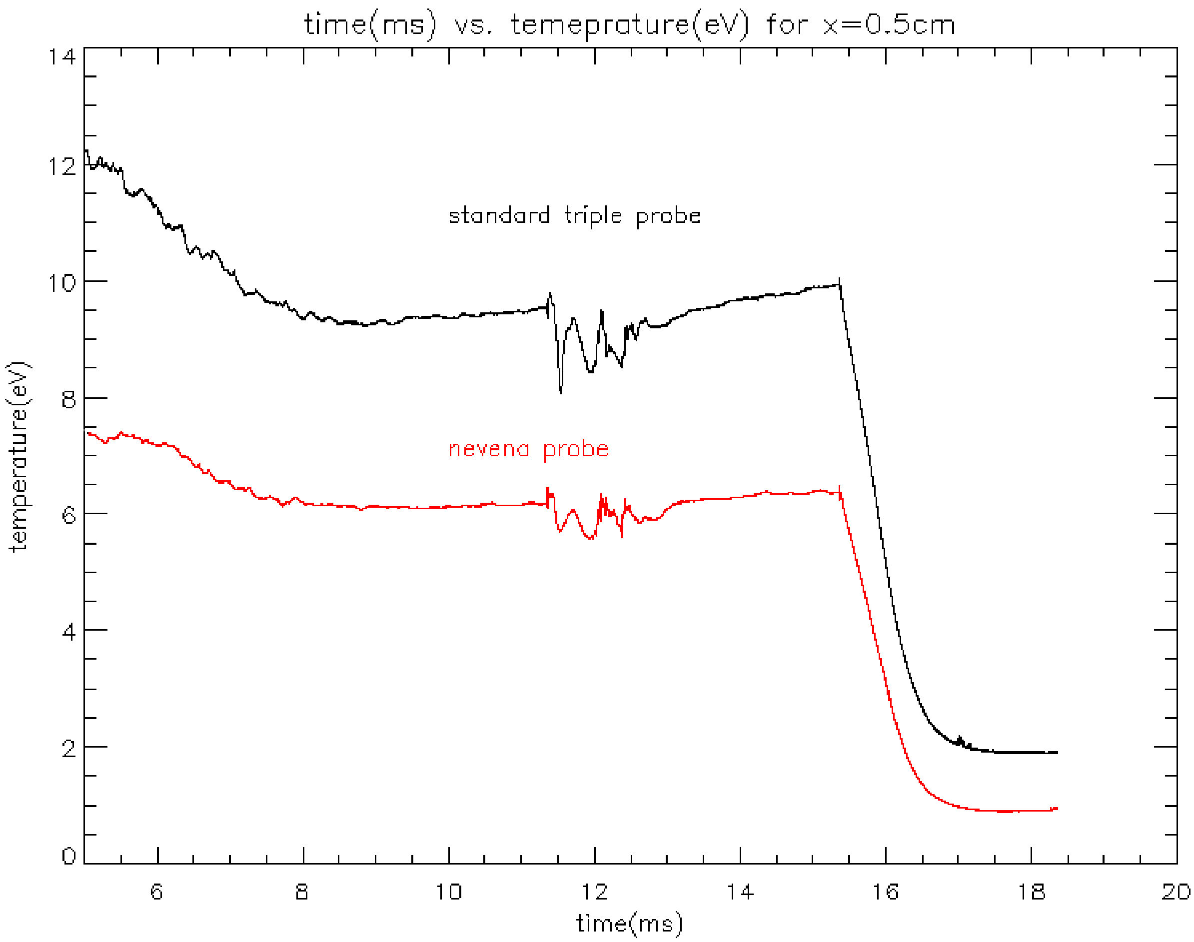

Figure 7: DC Temperature with current on, 'nevena' probe refers to the asymmetric triple probe

on the average temperature plot fluctuations are apparent (between 11-13ms).

Moreover, Figure 8 shows a drop in ion saturation current at a position where the copper structure is inserted and while the current is going through it. Since ion saturation current is proportional to density, this is the same trend one would expect for the density plot. A drop in density is to be expected since plasma is fully ionized by the time current starts flowing through the copper, so instead of ionizing the region further it depletes it. Furthermore, this leads to the creation of density gradients at the positions of approximately -2cm and 0cm, which are necessary for the existence of drift waves (can be seen on the RMS ($variance = RMS^2$) plot).

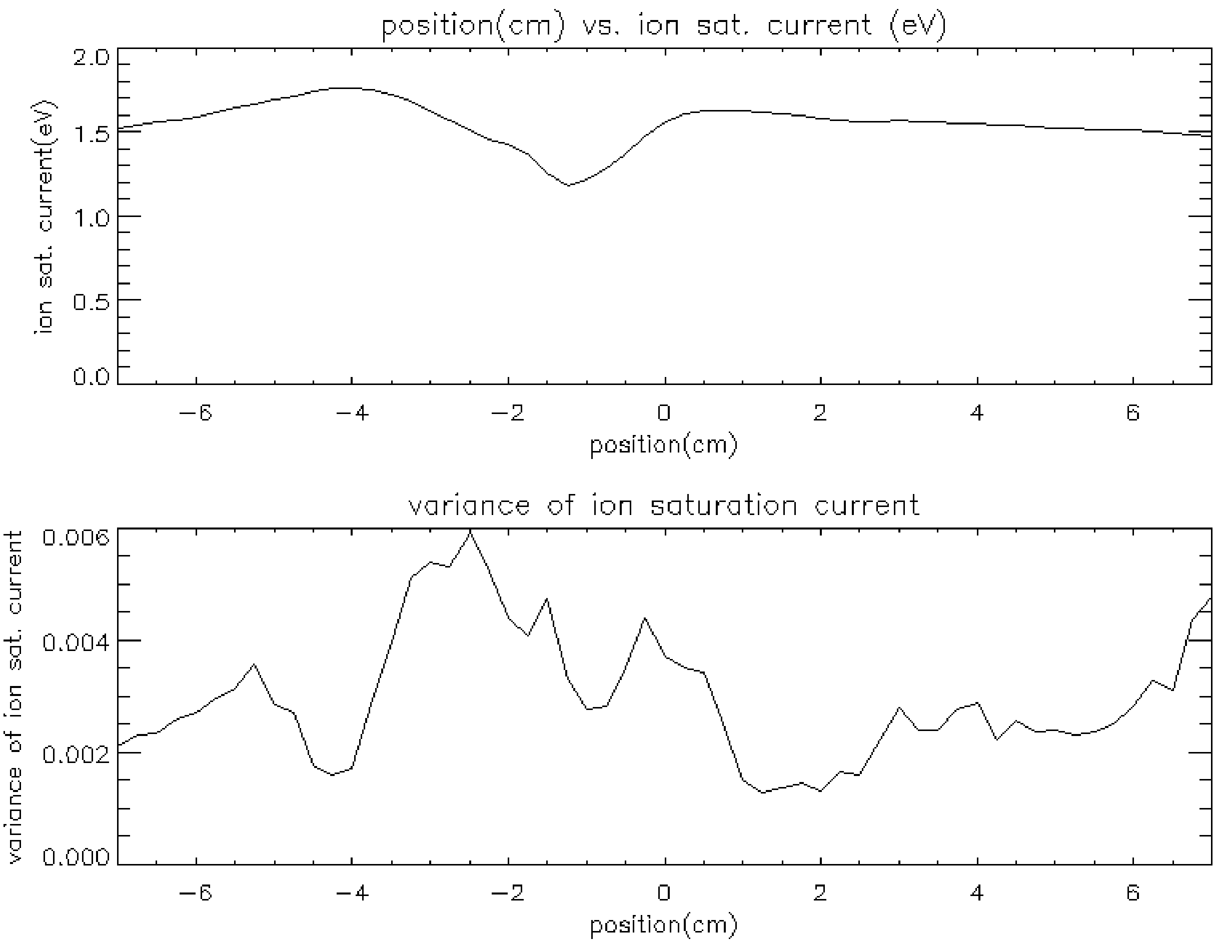

Figure 8: Density gradients

Drift waves are tube-like waves that arise at frequencies 10kHz-50kHz, at density and temperature gradients. They propagate in the azimuthal direction, causing creation of other waves and drifts (such as ExB drift that is responsible for the movement of plasma). Drift waves also arise in the magnetic confinement devices such as tokamaks and are responsible for cross field transport of particles' heat and momentum. However, since tokamaks are hot, a probe cannot be inserted to observe temperature fluctuations caused by drift waves. Thus, much cooler LAPD machine is used for their study.

To confirm the existence of drift waves, it is necessary to look at raw data (not the averaged one) and see what kind of fluctuations can be observed there. Even though averaged data does show some fluctuations, a big portion of them has been averaged to zero. Finding waves in the above mentioned frequency range in one of the density gradients would indicate that it is reasonable to assume that these are drift waves.

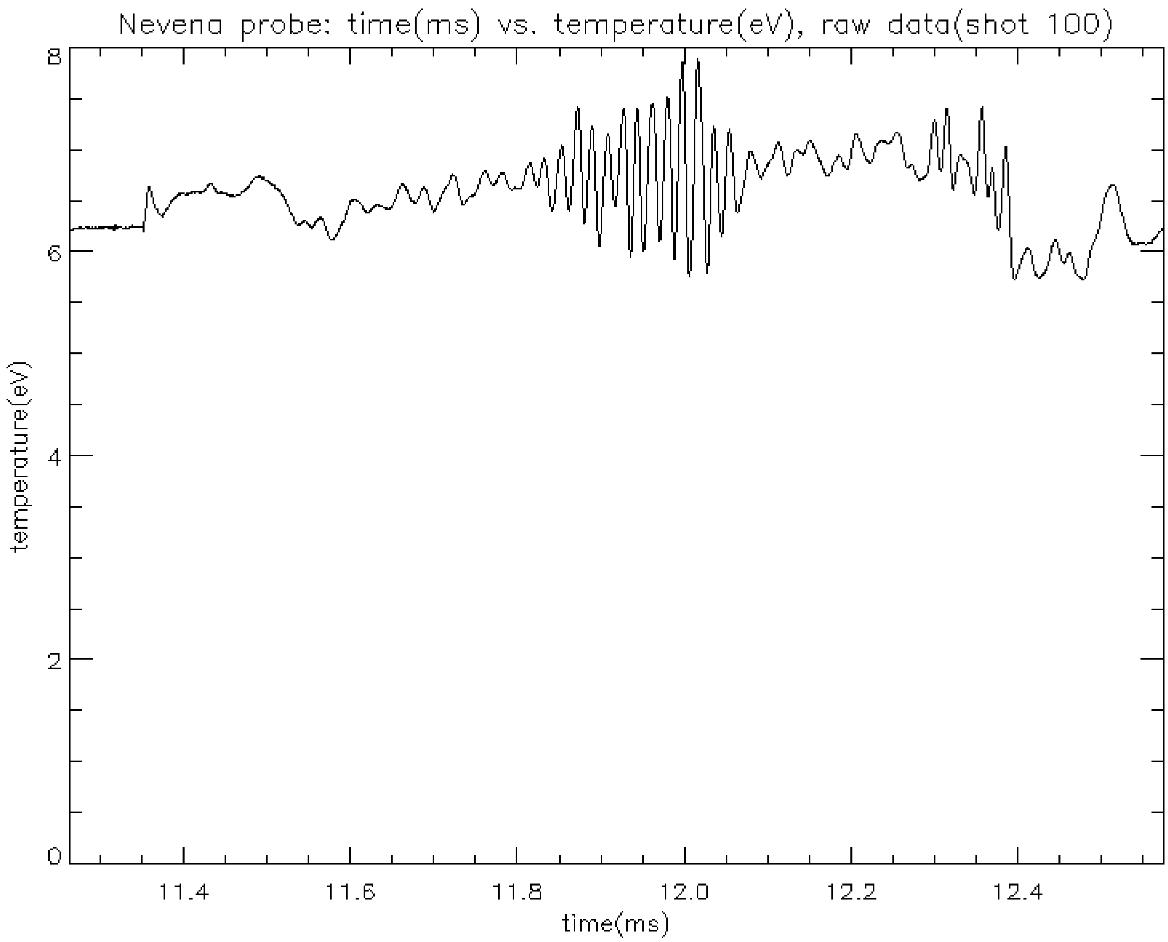

Figure 9: Raw temperature plot

Figure 9 is a plot of raw temperature at x=0cm (mentioned on pg.7 to be

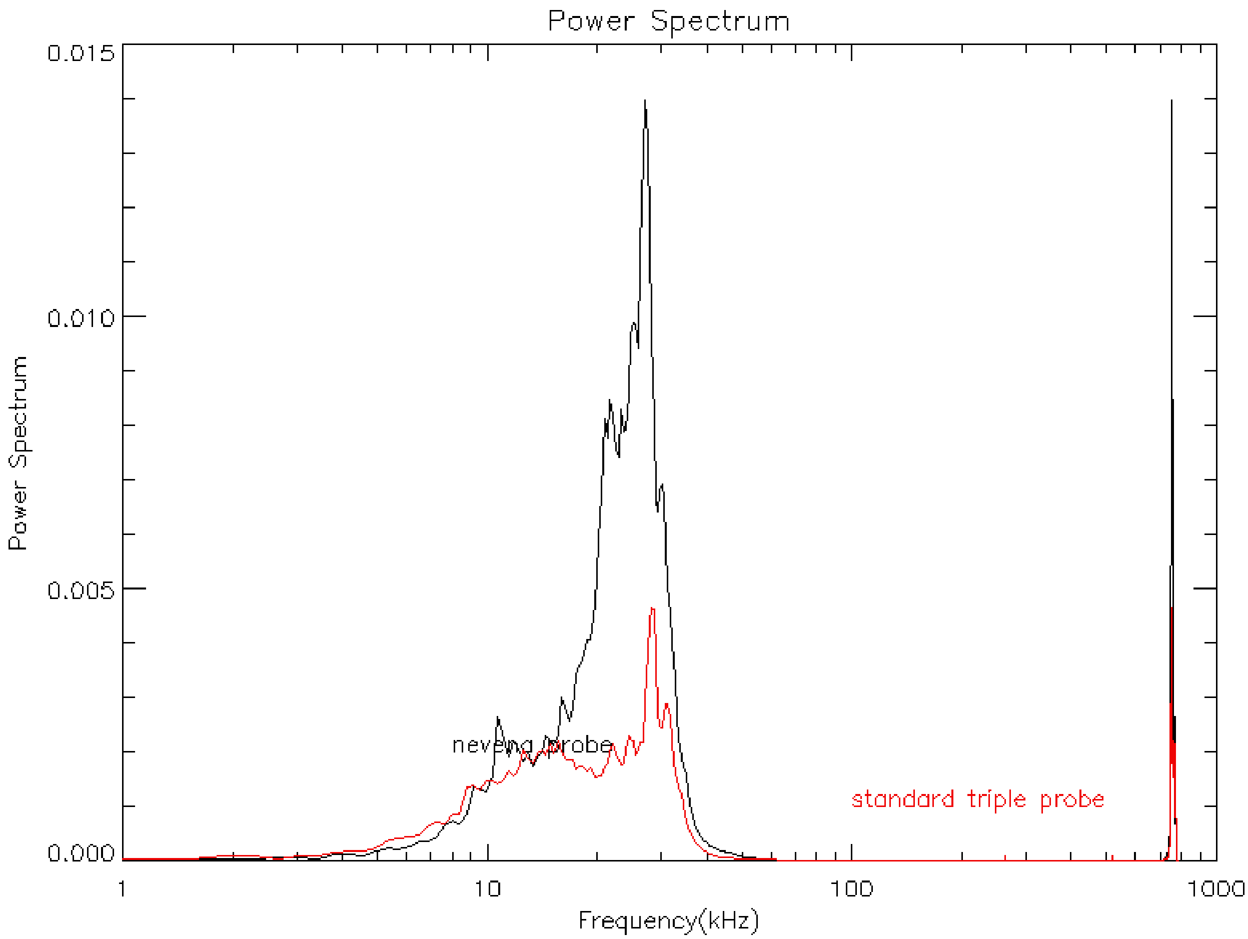

Figure 10: Power Spectrum, 'nevena' probe refers to the asymmetric triple probe

one of the density gradients). The plot is taken during the time interval when current was pulsed through the structure (between 11-13ms). Oscillations observed on the graph clearly indicate existence of the waves. By approximating the period of the waves (0.04 ms), frequency is found to be 25kHz, clearly lying in the drift wave range. Furthermore, we decided to go ahead and look at the power spectrum of Figure 9 in order to determine the most dominant frequency during this time period and see how our approximation compares to it. We were also interested in comparing sensitivities of two probes (standard triple probe and asymmetric triple probe) to the temperature fluctuations. As observed in Figure 10, both probes seem to show dominant frequency to be about 30kHz, which is somewhat in agreement with our approximation, thus indicating that observed waves are the most dominant waves in that time interval at x=0cm. Furthermore, belief that these waves are most likely drift waves has been reaffirmed. The asymmetric probe seems to show greater sensitivity to the temperature fluctuations than the standard triple probe. This leads us to believe that temperature fluctuations occur in the bulk electrons of Maxwellian distribution rather than the tail electrons, and so asymmetric probe is more sensitive to those changes.

5 Conclusion

The asymmetric triple probe proves to be superior over the standard triple probe when it comes down to measurements of average temperature in the plasma. It samples bulk electrons of Maxwellian distribution, and is more sensitive to temperature fluctuations in these regions than standard triple probe. However, standard triple probe does sample more of tail electrons and thus might be used for researching possible fluctuations in plasma regions characterized by its faster electrons.