Anomalous Ion Heating and Rotation During Radio Frequency Heating in NSTX

[Contact: mono@pppl.gov]

Alfvén waves, the most common type of waves found in the universe, are generated whenever magnetic field lines are disturbed (as one would pluck a violin string.) In nature, often violent magnetic reconnection events such as in solar flares can generate a wide spectrum of Alfvén waves, and have been cited as a possible cause for unexplained coronal heating. Interestingly, understanding these heating processes may also play an important role in improving heating and current drive efficiencies in magnetic fusion experiments.

Recently, rather unexpected "anomalous" ion heating was observed during "compressional" Alfvén wave (High Harmonic Fast Wave) HHFW heating in a controlled laboratory setting on the National Spherical Torus Experiment (NSTX) [1]. An innovative diagnostic to measure edge ion temperature and rotation rates from intrinsic photon emission has been implemented on NSTX. It is capable of measuring both perpendicular and parallel temperatures and toroidal and poloidal rotation velocities simultaneously at the outer mid-plane location. Ten-fold edge ion temperature increases accompanied by edge rotation have been observed with application of HHFW as shown in Figure 1. The hot component temperature increases roughly with the square root of the applied power, while the cold component remains unaffected. The observed ion heating is consistent with acceleration of ions perpendicular to the local magnetic field direction. However, such an ion acceleration was a surprise since there is no known direct wave absorption mechanism.

To understand the cause of this heating, an edge radio-frequency (RF) probe was placed near the RF antenna. The probe indeed revealed rather rich frequency spectra as shown in Figure 2. Normally the probe should only see the 30-Mhz applied wave frequency peak, but one can see prominent excitation of multiple "side-bands" separated by roughly the ion cyclotron frequency of the majority ion species. This excitation process is known as parametric decay instability, where a "pump" wave with sufficient amplitude can excite "daughter" waves according to the selection rule for frequency and wave number: $\omega_0 = \omega_1 + \omega_2$ and $k_0 = k_1 + k_2$. The subscript 0 denotes the pump wave and the subscripts 1 and 2 denote the daughter waves. The parametric instabilities permit excitation of much shorter wavelength electrostatic waves that are readily absorbed by the plasma. In the present case, a long wavelength Alfvén wave launched at 30 MHz (an electromagnetic wave) decays into two different electrostatic waves. One is a hot, magnetized ion cyclotron harmonic wave which propagates as a natural resonance of the plasma, and the other is an ion "quasi"-mode near the ion cyclotron frequency. Since the ion quasi-mode does not have to be a natural resonance of the plasma, this parametric instability process can be quite robust (easy to occur) and has relatively low power threshold. These short wavelength electrostatic modes can then interact strongly with the background plasma and efficiently transfer the energy into bulk ions.

Through this three-wave interaction process, the Alfvén wave energy can be converted efficiently into heating the bulk ion species even when the Alfvén wave is not normally expected to damp. It is estimated that a significant fraction of the launched power can be converted into ion heating [2]. The increased edge ion heating is accompanied by a reduction in the normally occurring core electron heating efficiency. Understanding this non-linear heating mechanism can therefore lead to improved efficiency of RF heating and current drive for magnetic fusion reactors. At the same time, it could also offer insight into the processes responsible for anomalous ion heating in solar coronas where the Alfvén wave energy generated through the magnetic reconnection process can be efficiently converted into the bulk ion energy.

Ref: [1] Ted Biewer: Invited talk at APS, RI1.001, Friday, Nov. 19.
[2] Stefi Diem: Contributed paper at APS, JP 1.014, Wed. afternoon Nov. 17.

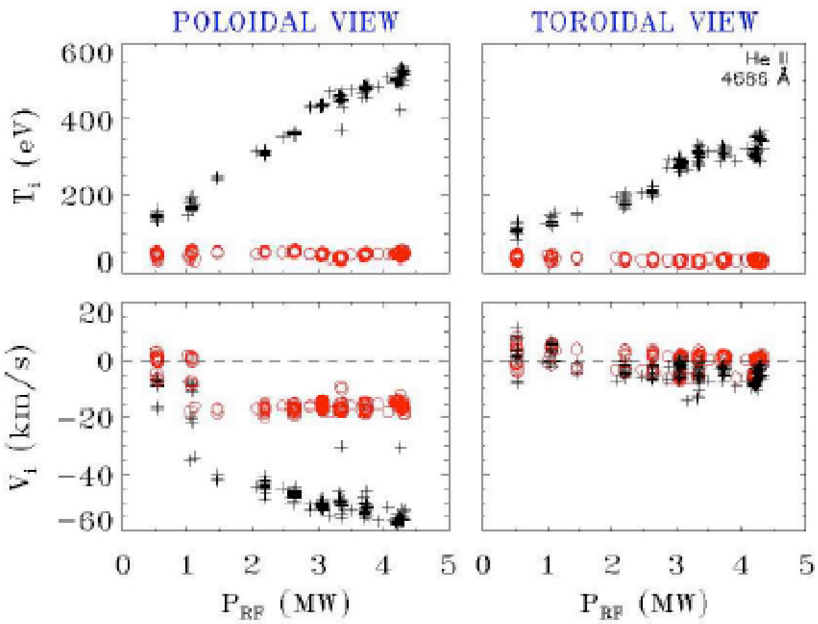

Figure 1 Anomalous ion heating and rotation during radio frequency heating, showing predominantly perpendicular heating and poloidal velocity acceleration.

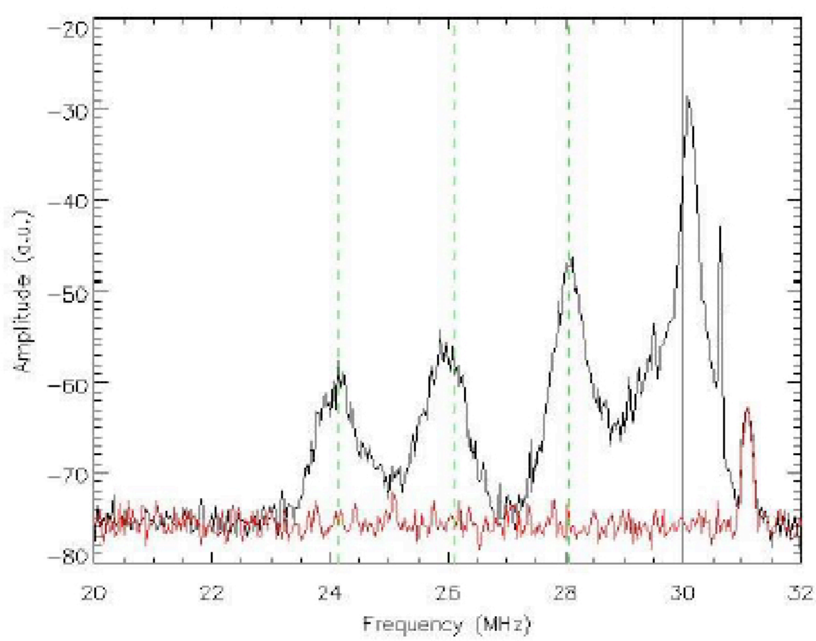

Figure 2 Parametric instability frequency spectrum showing multiple sideband IBW decay modes. The pump frequency is at 30 MHz.