Title: New High Temperature Laboratory Plasmas to Explore the Science of Space Plasmas

During the recent experimental campaign with high power heating, researchers on the National Spherical Torus Experimental (NSTX) successfully confined high-temperature (i.e. low-collisionality) plasmas at high beta, a condition where the central plasma pressure approaching that of the confining magnetic field [1]. While difficult to achieve in the laboratory, these conditions occur in many astrophysical and space plasmas. Using a powerful neutral beam injection (NBI) system as well as an innovative Compressional Alfvén wave heating technique, the core NSTX plasmas were heated to tens of millions of degrees Kelvin (both ions and electrons) [2]. The success of these heating techniques is a very good news for fusion concepts based on the spherical torus. In addition, this new laboratory plasma offers exciting prospects for investigating important astrophysical plasma phenomena such as interactions of Alfvén waves with background plasmas and energetic particles such as solar wind. Alfvén waves (named after its discoverer) propagate due to the inertia of plasma particles coupled with the springiness of ambient magnetic field, and considered the most common plasma waves in the astrophysical and space plasmas. At high beta, the Alfvén wave velocity slows toward the ion thermal velocity, creating a condition particularly conducive to these wave-particle interactions.

Compressional Alfvén waves at multiples of the ion-cyclotron frequency are launched into the NSTX plasma by a twelve-element antenna array where the toroidal phase velocity of the waves is controlled by adjusting the relative phase of the antenna elements. The waves launched in this high beta condition can interact strongly with plasma electrons through a process similar to the ocean waves accelerating a surfboard. In NSTX, the absorption of energy from the Compressional Alfvén wave gets so strong that the waves are essentially damped in less than one transit across the plasma. In previous lower beta experiments, multiple (≈ 10) transits were required for complete absorption. As shown in the figure, with application of 3.4 million watts of Compressional Alfvén wave power, the central electron temperature in NSTX rises continuously from about 2 million degrees Kelvin in the initial resistively heated phase to near 40 million degrees Kelvin (a 20 fold increase). These waves were observed to also accelerate energetic NBI ions at multiple ion-cyclotron frequencies [4]. These wave absorption processes may be relevant to the anomalous electron heating observed in the solar corona and to a possible acceleration mechanism for creating energetic ion populations recently observed in the solar wind.

In another series of experiments with NBI, the creation of a substantial population of energetic ions with velocities much faster than the Alfvén wave phase velocity (super Alfvénic) excited a rich variety of Alfvén waves, both shear and compressional, [5]. This type of wave-particle excitation/absorption process could, for example, explain the mystery of the large corona ion temperature observed by the NASA TRACE satellite [6].

[1] S. Sabbaugh et al., invited paper BI1.003.
[2] R. Bell et al., invited paper LI1.002.
[3] J. R. Wilson et al., oral presentation GO1.001.
[4] A. Rosenberg et al., poster presentation GP1.010
[5] E. Fredrickson et al., invited paper LI1.003.
[6] R. White et al., invited paper FI1.006.
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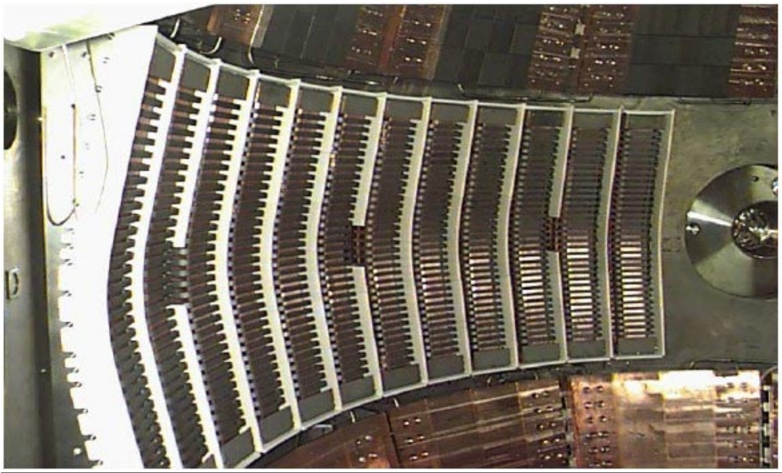
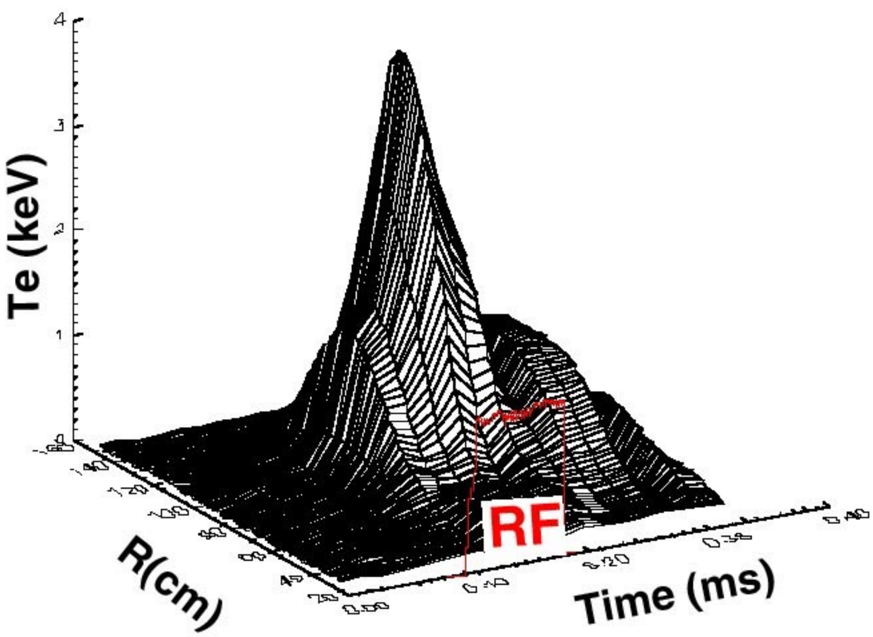


Twelve-element-rf antenna array for launching
real-time-phase-controlled compressional
Alfven waves in NSTX



Application of compressional Alfven wave heating produced very high central electron temperature and pressure in NSTX, where electrons were heated from 2 million degrees Kelvin to nearly 40 million degrees Kelvin.