**A New Type of Electromagnetic Wave Observed in Tokamak Plasmas with High Power Radio Frequency Heating**

In magnetically-confined fusion experiments, the plasmas need to be heated to the temperature of hundreds of million degrees. To achieve this temperature, radio frequency (rf) waves are often used to heat the plasma. In the Alcator C-Mod tokamak located at the Plasma Science and Fusion Center at MIT, 8 million watts rf sources at about 80 MHz are available. At this frequency (close to the broadcast frequency of TV Channel-5), the hydrogen ions in the plasma resonate with the rf waves at the typical magnetic field (5.4 Tesla) in Alcator C-Mod. The resonant hydrogen ions then transfer energy to the bulk plasma deuterium ions (an isotope of hydrogen composed of a proton and a neutron) so that the entire plasma is heated up. However, this seemingly simple heating scheme is very complicated in a tokamak plasma. The heating is most efficient when there is only a few percent of hydrogen in the mostly deuterium plasma. When the hydrogen concentration is higher, say, more than 10 percent, the launched rf waves from the rf antennas, which typically have wavelengths of 5 to 10 cm, may be converted to waves with wavelengths of a few centimeters or less. This so-called mode conversion (MC) process happens in the vicinity in a layer named ion-ion hybrid layer, whose location is determined by the plasma species mixture. In contrast to the ion resonance heating from the launched wave, these shorter wavelength waves transfer their energy to the electrons in the plasma. One of the MC waves, the ion Bernstein wave (IBW), is well-known by plasma physicists and has been studied in detail. In Alcator C-Mod, the MC IBW usually has a wavelength of a few mm and stays on the side of the ion-ion hybrid layer with higher magnetic field. In recent experiments in Alcator C-Mod, a second wave, the ion cyclotron wave (ICW), has been observed for the first time in tokamak plasmas by means of phase contrast imaging, a laser based interferometric diagnostic technique. The ICW has a wavelength of about 1-2 cm and appears on the low field side of the ion-ion hybrid layer. The locations of the IBW and ICW are shown in figure 2. Through numerical studies, we have found that the appearance of this MC ICW is the result of the sheared magnetic field configuration in the tokamak, where magnetic field lines are twisted because of the toroidal plasma current. The observation and identification of the MC ICW show that the MC process of rf waves in tokamak plasmas is much more complicated than previously thought. The MC ICW is expected to dominate over the MC IBW in typical plasmas of deuterium and tritium (another isotope of hydrogen with a proton and two neutrons) in future fusion reactors. As a result, the physics of mode conversion to ion cyclotron waves can have important applications, including current drive and flow drive, in high power rf heated tokamak experiments.

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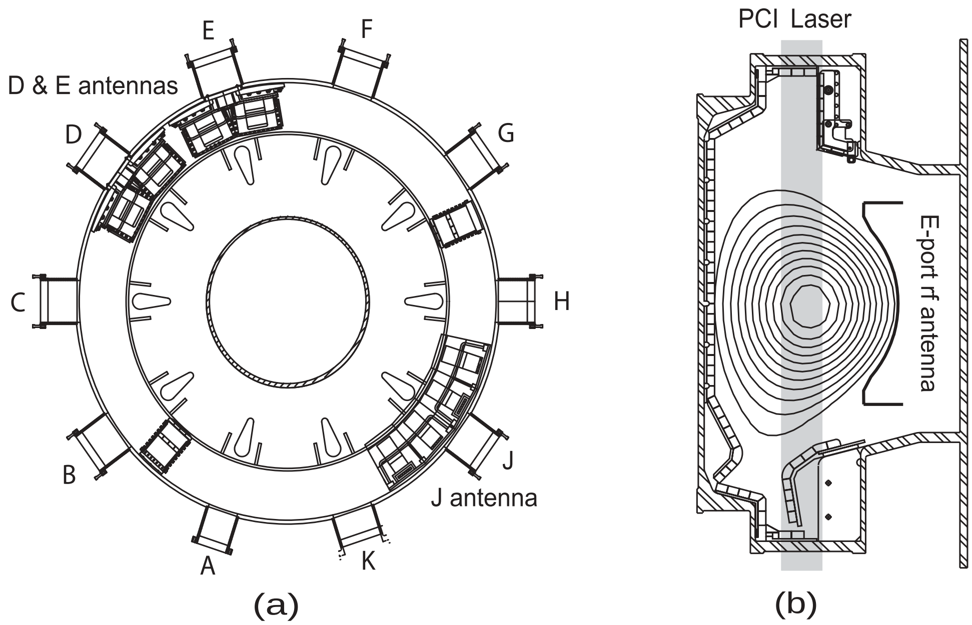


Figure 1: (a) The top view of the Alcator C-Mod tokamak. The rf antennas are located at 3 toroidal locations. (b) The phase contrast imaging system shown in the cross-section of the tokamak. The $CO_2$ laser beam, used to measure density fluctuations driven the rf waves, is indicated by the shaded area.

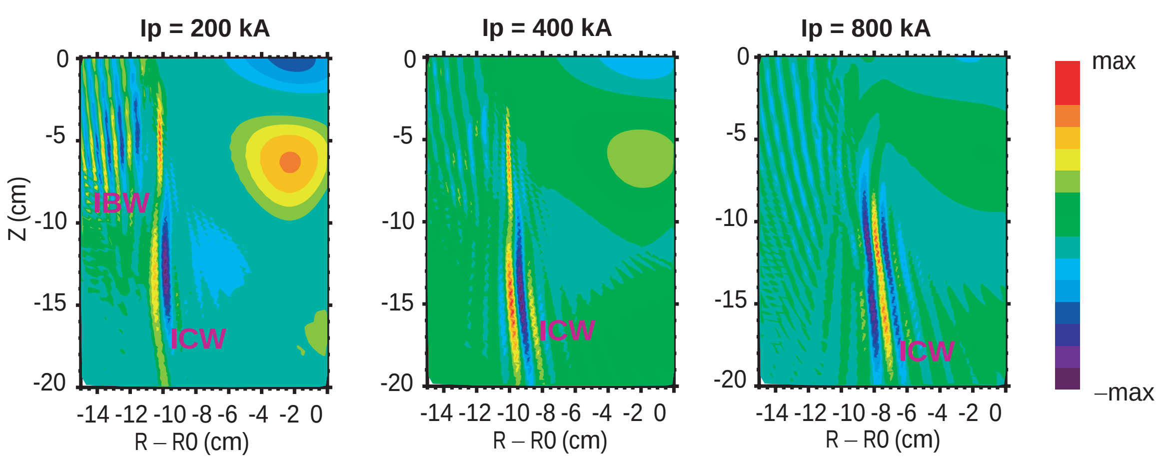


Figure 2: As plasma current ($I_p$) is raised, the magnetic field helicity is increased, and the mode conversion process progressively favors the ion cyclotron wave over the Bernstein wave. The 2-dimensional false-color contours of electric field of the waves are shown in the three plots for increasing value of $I_p$. The contours are obtained from numerical simulations. $R - R_0$ is the horizontal distance from the center of the plasma, and $Z$ is the vertical distance.