Intense radio waves used to create and control high density cores in magnetic fusion energy experiments

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Making fusion power means achieving high densities and high temperatures in a controlled way. To achieve fusion energy production, the goal is to reach very high pressures, similar to the sun. The high pressure, which is the product of density and temperature, must be maintained so that fusion reactions occur frequently and continuously. Researchers at MIT have learned to create and control very high density cores by beaming over two million watts of radio waves into the Alcator C-Mod tokamak, in a way that heats the plasma both on- and off-center. More recently, the MIT team has found that they can improve the size of this high density region by controlling the magnetic fields and currents in the target plasmas. It was surprising that heating off-center leads to formation of a "transport barrier" for particles, causing the core density to triple inside the heating location. Why would radio waves cause more and more particles to stream into the plasma core?

It is generally known that fine-scale turbulence, driven by the temperature gradient, develops in the plasma, causing heat and particles to diffuse outward from the core. For the MIT experiments, supercomputer simulations of this fine scale turbulence, using the equivalent power of over 2500 personal computers, show that turbulence is reduced because the off-center heating flattens the temperature profile inside the heating location. At the same time, the turbulence actually reverses the particle flow from outward to inward, causing the density to pile up in the core. With purely off-center heating, the plasma core gets more and more dense until it finally collapses by radiating away all of its power. The MIT experiments have demonstrated that the core density can be controlled and maintained at a constant value, preventing collapse, by turning on lower power radio waves that heat the plasma center. Supercomputer simulations of turbulence in these experiments show that when the density gradient steepens, it drives another type of turbulence (trapped electron modes) that counters the inflow, producing an outflow. The results of the simulations agree with the experimental measurements. The comparison is simplified because there is no core fueling source, similar to future reactors. The simulations show the on-center radio frequency heating increases the outflow of particles by increasing the temperature, which provides the mechanism for controlling the density with central heating. This remarkable ability to create and control internal transport barriers using only radio waves, and the understanding of it achieved through first principles supercomputer simulations, are a significant advance in magnetic fusion research.

Note: These results are not yet published and will be submitted for publication in the Special Issue of Physics of Plasmas, to appear in May (2004). Supercomputer simulations were performed at the National Energy Research Supercomputer Center in Berkeley, CA.

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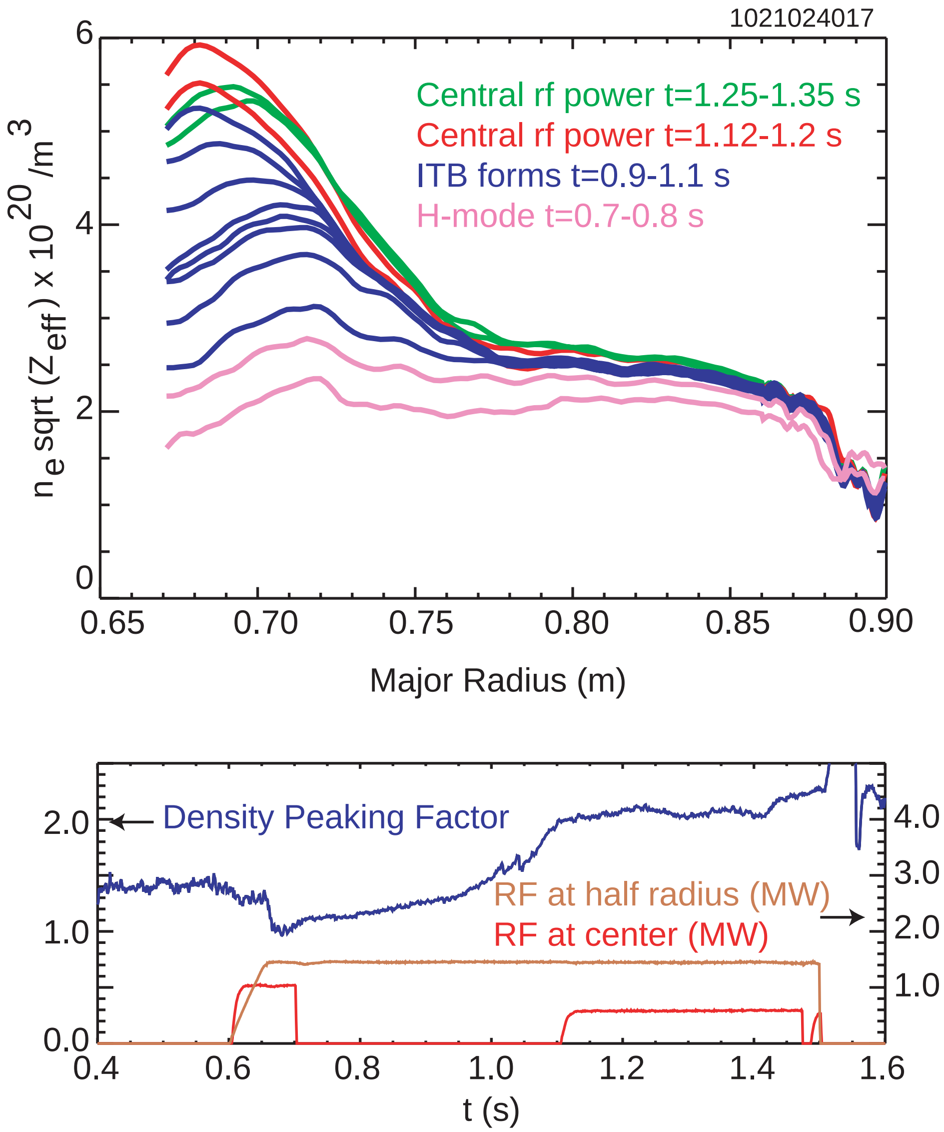

Figure 1. The top plot shows the evolution of the plasma density profiles as time progresses. The transport barrier occurs inside of Major Radius (R) =0.77 m, with the center of the plasma located at R=0.69 m. After the barrier is formed (t = .8 s), addition of on-axis plasma heating after t=1.1 seconds arrests the central density buildup. The bottom plot shows the time evolution of the density peakedness (ratio of core to edge densities), along with the traces showing off-axis (half-radius) and central heating powers.