New experiments control density in the core of a fusion plasma using radio waves

The turbulence responsible is directly measured, and supercomputer simulations of it closely match experiments, revealing new secrets of the inner core.

NEW ORLEANS – Fusion experiments on the DIII-D tokamak at General Atomics (San Diego) and the Alcator C-Mod tokamak at MIT (Cambridge, Massachusetts), have demonstrated that radio waves can be used to control the density and impurity content in the inner plasma core, where a fusion reactor would produce most of its power. The radio waves mimic the way fusion reactions would supply heat to electrons to keep the "fusion burn" going. The new experiments reveal how turbulence in the inner core changes when most of the heat goes to electrons. Supercomputer simulations closely reproduce the experiments, showing that a type of turbulence, called Trapped Electron Mode (TEM) turbulence, intensifies. The TEM turbulence reduces the density by transporting particles along with heat. The work shows that this type of turbulence acts like much like a "governor" in a gasoline engine, which could help produce a steady fusion burn, say the researchers.

"We are beginning to uncover the fundamental mechanisms that control the density, under conditions relevant to a real fusion reactor," says Dr. Darin Ernst, a physicist at the Massachusetts Institute of Technology, who led the experiments and simulations, together with co-leaders Dr. Keith Burrell (General Atomics), Dr. Walter Guttenfelder (Princeton University Plasma Physics Laboratory), and Dr. Terry Rhodes (UCLA). The experiments were conducted by a team of researchers under the first National Fusion Science Campaign. This new program, overseen by a committee of representatives from the major U.S. fusion facilities, enables research on one machine to be expanded and tested on another facility with complementary diagnostics and capabilities. "The National Campaign has increased the impact of our work, with added benefit to the fusion program," says Dr. Ernst. "Comparing Alcator C-Mod and DIII-D tests our new predictions that particle collisions strongly reduce this type of turbulence. The collision rate varies by a factor of ten between the two machines," says Ernst.

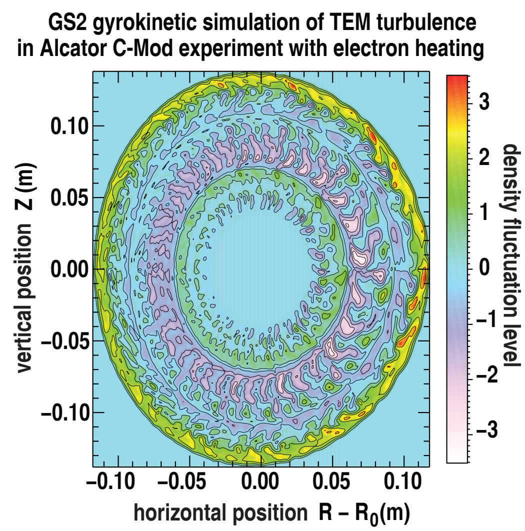

Figure 0: Supercomputer simulation of TEM turbulence in the Alcator C-Mod tokamak during strong electron heating (courtesy D. R. Ernst, MIT).

The experiments and simulations suggest that TEM turbulence becomes more important under the conditions expected in self-heated fusion reactors. The structure of the simulated turbulence during heating by radio waves is shown in Fig. 1. A significant result is that the simulations closely matched detailed measurements of the actual turbulence in the inner core. "We discovered that sheared flows drive turbulence in the inner core, but as we approached conditions where mainly the electrons are heated, this effect tends to go away and TEM turbulence begins to dominate," says Dr. Guttenfelder, who did the simulations of turbulence for the DIII-D experiments, along with Dr. Andris Dimits (LLNL). Measurements revealed a band of fluctuations, separated by a constant frequency interval, like harmonics in a musical note.

“These new coherent fluctuations (Fig. 2) appear to be consistent with the basic TEM instability that grows stronger during heating, “ says Dr. Rhodes.

In a self-heated fusion reactor, fusion reactions produce energetic alpha particles. The alpha particles are charged, so they follow the magnetic field lines, but like bulls in a china shop, they knock the electrons in their path out of the way. This is a good thing, because it heats the electrons by imparting random thermal motion. The electrons in turn collide with and heat the deuterium and tritium ions, which are the fuel. In a real reactor, the ions will be heated until they reach the same temperature as the electrons. The problem is that turbulence gets in the way. Turbulent eddies swirl the particles, forming a bucket brigade that carries particles and energy away from the hot core toward the edge, where they eventually disappear. “It’s important to understand what drives the turbulence, and how it can be controlled, and to find new ways of operating that exploit that knowledge,” says Dr. Burrell.

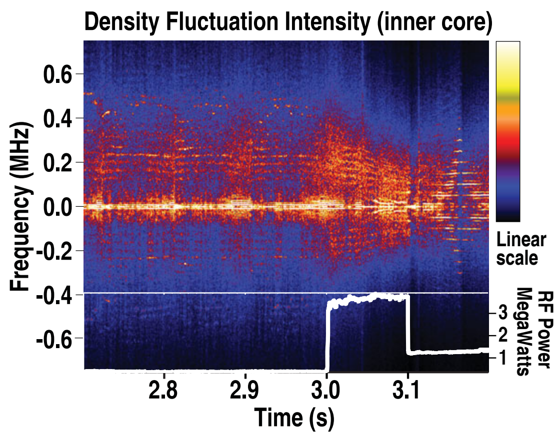

Figure 1: Measured density fluctuations in the inner core. The newly discovered band of frequencies between 0.1 and 0.4 MHz are the coherent fluctuations. When the 3.4 mega-Watts of radio frequency electron heating is turned on at 3.0 seconds, the fluctuations intensify and the inner core density is reduced by the turbulence (courtesy T. Rhodes (UCLA).

To shed further light on turbulent energy and particle loss under fusion-relevant conditions, the team has also done another series of experiments that use radio wave heating to systematically vary the temperature gradient in the outer half of the plasma. By comparing detailed turbulence measurements with simulations, they hope to understand how turbulence controls the core temperature under realistic conditions.

This material is based upon work supported in part DE-FC02-08ER54966, by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, using the DIII-D National Fusion Facility, a DOE Office of Science user facility, under Awards DE-FC02-04ER54698, DE-FC02-04ER54698, DE-AC02-09CH11466, DE-FG02-08ER54984, and DE-AC52-07NA27344.

Contacts:

D. Ernst, MIT (617) 253-0478, dernst@psfc.mit.edu
K. Burrell, General Atomics (858) 455-2278, burrell@fusion.gat.com
W. Guttenfelder, PPPL (609) 243-2426, wgutten@pppl.gov
T. Rhodes, UCLA (858) 455 2437, trhodes@ucla.edu
A. Dimits, LLNL (925) 422-0211, dimits1@llnl.gov

Abstracts:

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Controlling DIII-D QH-Mode Particle and Electron Thermal Transport with ECH
Speaker: D. R. Ernst (MIT)
2:12 PM–2:24 PM, Monday, October 27, 2014
Galerie 2/3