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# Imaging of Alfvén Waves and Fast Ions in a Fusion Plasma

*New techniques give scientists detailed images of processes critical for the development of fusion reactors*

Fusion plasmas in the laboratory typically reach 100 million degrees. These high temperatures are required to ignite the hydrogen plasma and maintain the fusion burn by the production of high-energy alpha particles. One challenge for a fusion reactor is how to contain the alpha particles in the vessel long enough for the particles to efficiently heat the hydrogen plasma. One way that these alpha particles can escape the fusion chamber prematurely is by exciting high frequency Alfvén waves and riding these waves to the vessel walls, like a surfer rides a wave to the beach.

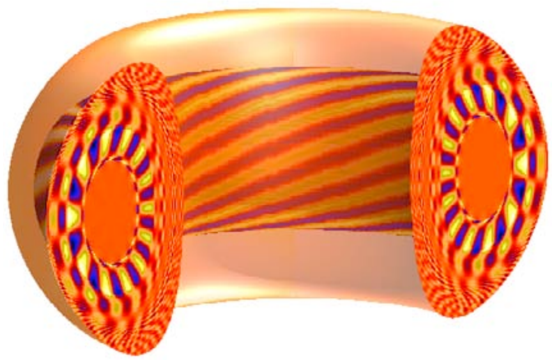

Fig. 1. Calculation of a typical Alfvén wave in the DIII-D tokamak.

While it is easy to sit on the seashore and watch surfers riding waves to the beach, it is far more challenging to see the alpha particles riding Alfvén waves to the walls of a fusion reactor. Recently, researchers have provided the first 2-D visualization of the elegant 3-D spiral pattern of these Alfvén waves together with the observation of the energetic particles that ride these waves to the walls of the reactor (Fig. 1). The breakthrough allowing the measurement of these Alfvén waves is the development of a highly sensitive camera designed to measure minute temperature fluctuations inside the plasma that indicate the presence of these Alfvén waves. These results will be presented at the American Physical Society Division of Plasma Physics 52nd annual meeting, November 8–12, in Chicago, Illinois by researchers from DIII-D National Fusion Facility and the ASDEX Upgrade tokamak.

In the experiments on the DIII-D tokamak, beams of high-energy particles are injected into the plasma to simulate the alpha particles expected in a fusion reactor. These particles then excite Alfvén waves similar to what's expected in a reactor and under the right conditions they can ride these waves to the wall. By studying the behavior of the energetic particles and Alfvén waves, we can learn a great deal about what to expect in a fusion reactor.

Unprecedented images of these Alfvén waves have recently been obtained by recording the variation in the plasma temperature using a special camera. These cameras are basically heat detectors, much like IR cameras used to image thermal objects at night. However the camera developed on DIII-D is optimized for resolving tiny variations in the plasma temperature by measuring the "heat" radiated in the form of microwaves, much like the radiation emitted by a microwave oven.

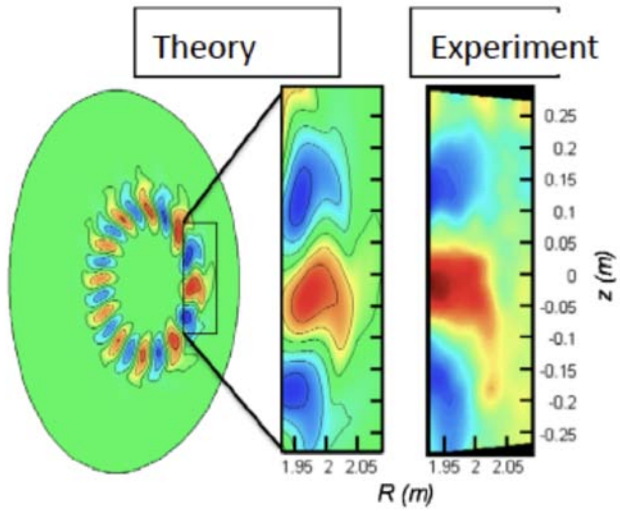


Fig. 2. Inset: 2D microwave imaging data compared to the predicted temperature perturbation for an Alfvén wave in DIII-D.

The fusion plasma has a torus shape and the plasma waves spiral around the torus as shown in Fig. 1. Also shown in Fig. 1 is a 2-D cross section of the waves taken by slicing the torus. It is this cross section view that the new imaging system is measuring. Figure 2 shows a comparison of an image of one of these Alfvén waves in DIII-D compared to the calculated wave structure predicted by theory. Many features of the theoretical prediction of these waves are observed in the image such as the location of the waves in the plasma, the wavelength of the wave and the twisting spiral pattern of the wave.

In addition to these remarkable images of the Alfvén waves, new measurements have been obtained of the particles that excite these waves and ride the waves to the walls.

Recently, a technique has been developed to directly measure ions that strike the wall after riding the Alfvén waves out of the plasma. A phosphor screen is used that lights up when struck by these escaping particles and a camera is used to image the phosphor. The pattern of the light on the screen provides specific information on the energy and direction of the particles arriving at the wall. Fast images of the phosphor show bunches of beam particles arriving to the wall synchronized with the arrival of the Alfvén waves. This is similar to watching multiple surfers riding a single wave, where these surfers all arrive at the beach together.

Thanks to the focused effort of a large international collaboration, modeling efforts to simulate these recent experiments are now able to reproduce many of the features of both the Alfvén wave structure and the particle losses. These same codes are presently being used to predict the presence of Alfvén eigenmodes in ITER and initial results show that modes similar to those observed in DIII-D and ASDEX-Upgrade will be present. A key challenge for the future is to find ways of suppressing these Alfvén waves in a fusion reactor or at least minimizing their effect on the alpha particles.

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