Lifting Fusion Power onto an (Optimized) Pedestal

New insights into a fusion plasma's transport barrier promise to boost future reactor performance.

DENVER— In a collaborative effort, researchers in the United States and the United Kingdom have developed a new technique that will help them optimize the transport barrier, or pedestal, in fusion plasmas, which will be key to increasing future fusion power performance. This work has been recognized with the 2013 APS John Dawson Award for Excellence in Plasma Physics Research.

The core of fusion plasmas must reach temperatures over 100 million degrees to enable ample fusion power production. But the far edge plasma, which is in contact with material surfaces, must remain relatively cool. High performance, or "H-mode" operation, is achieved via the formation of an insulating transport barrier in the edge region of the plasma, which lifts the core. This transport barrier acts like the wall of a thermos bottle, separating the very hot plasma core (far hotter than the core of the sun) from a cooler layer of unconfined plasma and the material surfaces. The transport barrier is often referred to as a "pedestal," because it lifts the core plasma up to high temperature and pressure. Generally, the higher the pedestal, the more fusion power will be produced, with predictions for ITER and demonstration magnetic fusion power plants finding that fusion power increases with the square of the pedestal pressure.

Theoretical physicists at General Atomics in San Diego and the University of York in the United Kingdom, working with experimental physicists at the DIII-D tokamak in San Diego, have unveiled key physics that governs the pedestal. One critical finding is that the pedestal is limited by intermediate wavelength instabilities, driven by pressure and current gradients in the pedestal region. These instabilities are known as "peeling-ballooning" (PB) modes, because they balloon outward and peel off part of the insulating layer of plasma (Figure 1a). Extensive studies have clearly identified these modes in tokamak plasmas, and found that the pedestal pressure varies as predicted by PB calculations.

Recently, a model known as EPED has been developed, which combines PB calculations with calculated pressure gradient limits resulting from smaller scale instabilities known as kinetic ballooning modes. The EPED model can self-consistently predict the pressure and the width of the pedestal, and has been extensively tested in hundreds of experimental cases (Figure 1b).

Comparison of EPED Model to 270 Cases on 5 Tokamaks

- DIII-D ELM (91)
- DIII-D QH (11)
- C-Mod (10)
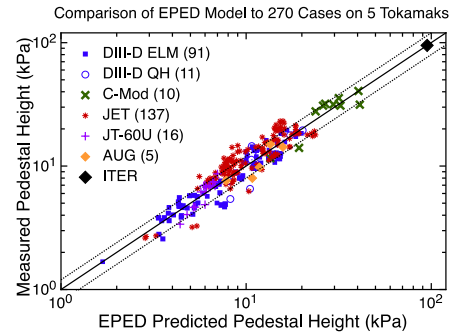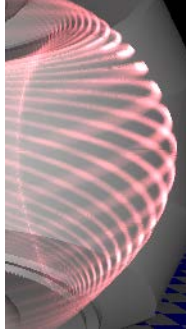- JET (137)
- JT-60U (16)
- AUG (5)
- ITER

Figure 1: (a) Typical structure of a peeling-ballooning mode in the DIII-D tokamak, calculated by ELITE. (b) Comparison of pedestal height predicted by the EPED model with observations on 5 tokamaks, with a prediction for ITER also shown.

Using EPED, it is possible not only to predict the pedestal in existing experiments, but to devise methods for optimizing pedestal and fusion performance. One important technique involves selecting plasma shapes which are strongly stabilizing to PB modes, such as highly elongated "D" shapes. In addition, new experiments have demonstrated that the injection of gases such as neon into the edge plasma can increase collisionality, reducing the current and stabilizing current driven PB modes. Combining these techniques has led to very high pedestal pressure and high overall performance in DIII-D. The same methods are being applied to predicting and optimizing the pedestal in the planned ITER device to enable high fusion performance.

See also: P.B. Snyder et al., Phys. Plasmas 19 056115 (2012).

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Abstracts:
YP8.00055   **Effect of Collisionality on H-mode Pedestal Structure**
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                           9:30 AM–9:30 AM, Friday, November 15, 2013
                           Room: Plaza ABC